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Response of Permanent Pastures to Lime and Fertilizers [1930 to 1936]

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Response of Permanent Pastures to Lime and Fertilizers (1930 to 1936)†

by R. R. ROBINSON and W. H. PIERRE‡

INTRODUCTION

The importance of permanent pastures in West Virginia agriculture arises from two general facts, namely: (1) pastures furnish the cheapest feed produced on the farm, and (2) pastures protect the soil from erosion and provide the best land-use possible on a large proportion of the farm land. According to the 1935 census, permanent pastures constitute 62 percent of the cleared farm land in the state. Yet no other important crop has been so neglected in this state.

The extent to which permanent pastures hae been neglected in West Virginia is well shown by a recent study of 775 representative pastures situated in different sections of the state. *(7)** In over 50 percent of the pasture area studied at least five acres were needed to pasture one 1000-pound animal, and only about 10 percent of the area was able to support an animal on two acres or less. Kentucky bluegrass, white clover, and other desirable pasture plants were found to average less than one-fourth of a stand, whereas weeds averaged 20 percent, poor native grasses 30 percent, and bare space 25 percent.

Impoverished soil is the main reason for the poor type of vegetation and the low carrying capacity of many West Virginia pastures *(7, 9)*. By the use of lime and fertilizers it has been found that the productivity of permanent pastures can be greatly increased *(5)*. Many questions still remain however, regarding the response to lime and fertilizers that may be expected on different soil types and on soils impoverished to various extents by erosion, by grazing, and by previous cropping. Moreover, relatively little is known about the residual effect from fertilizers and lime. Soil fertility experiments with pastures are more difficult and more expensive to conduct than similar experiments

†The investigations herein reported were conducted in cooperation with the Division of Forage Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture.

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*Reference by number is to Literature Cited, p. 46.

with most general farm crops, and relatively few experiments are available to show what may be expected over a period of years from proper pasture treatment and management.

In order to get some additional information on this problem, the present study was undertaken in 1930 in cooperation with the Bureau of Plant Industry of the United States Department of Agriculture. The main objectives of the experiments were as follow:

(1) To compare the response of permanent pastures on different soil types to various lime and fertilizer treatments, as measured by
  (a) Changes in the botanical composition of the vegetation.
  (b) Yield of forage.
  (c) Chemical composition of the forage.

(2) To study the relationship between the chemical composition of the soil and the response of pastures to lime and fertilizer treatments.

(3) To determine the residual effect of these treatments over a period of years and to study the downward movement of lime and phosphorus into the soil.

These experiments represent a total of 516 small plots located on seven soil types in different sections of the state. In addition, an experiment involving the use of plots of 4½ to 6 acres each was established in one of the experimental areas in cooperation with the Department of Dairy Husbandry for the purpose of comparing the increases in yields measured by grazing with those obtained by clipping. The results of the grazing experiment will be only briefly referred to in this publication but will be reported in more detailed form in another bulletin of the Agricultural Experiment Station.

PLAN AND DESCRIPTION OF THE EXPERIMENTS

The experiments were conducted on permanent pastures situated in various parts of the state in order to obtain a better knowledge of the effect of fertilizer and lime treatments on different soils and under various climatic conditions. Table 1 shows the location of the experimental areas, the dates the experiments were started, the soil type, depth of surface soil, and certain chemical properties of the soil. The Dekalb soils, which are derived from non-calcareous shales and from sandstones, are considered to be among the least productive of the upland soils, yet they will produce very good crops if limed, fertilized, and properly managed. The Upshur and the Westmoreland soils are derived partly from calcareous materials and are somewhat more productive than the Dekalb. The Huntington is a fertile bottomland soil derived from the wash of limestone uplands. The Monongahela and Holston are terrace soils derived from non-calcareous material. None of the areas selected for the experiments is found on slopes of more than about 15 percent. Erosion had removed considerable amounts of topsoil, and

TABLE 1—*General description of the experimental pasture areas*

Location	Date started	Soil type	Depth of surface soil (inches)	Chemical properties of the 0-3 in. soil layer: pH[1]	Readily available P[2]	Total N (%)	Exchangeable K (m.e./100 gms.)
Morgantown, Monongalia Co.	Spring, 1930	Dekalb silt loam	6	5.0	10	.184	.16
Aurora, Preston Co.	Spring, 1930	Upshur clay loam	4	5.4	9	.200	.26
Moorefield, Hardy Co.	Spring, 1930	Huntington silt l.	10	5.8	21	.211	.28
Maidsville, Monongalia Co.	Spring, 1931	Westmoreland silt l.	8	5.8	14	.194	.20
Wardensville, Hardy Co.	Spring, 1932	Monongahela fine sandy loam	8	4.9	12	.086	.11
Spencer, Roane Co.	Fall, 1934	Upshur clay	1½	4.9	9	.177	.43
Palestine, Wirt Co.	Fall, 1934	Holston silt loam	6	5.3	<5	.106	.19

[1]Low pH values mean high acidity; pH 5.0 or below is strongly acid; pH 6.0 is moderately acid; above pH 7.0 is alkaline.

[2]Determined by Truog's laboratory method *(11)* and expressed as pounds per 2,000,000 pounds of air-dry soil. It was found in other investigations *(7, 9)* that for pasture soils, at least 20 pounds of readily available phosphorus are necessary to insure a good sod of Kentucky bluegrass and white clover, and that less than 10 pounds can be considered very deficient.

TABLE 4—*Lime treatments per acre on the experimental pastures*[1]

Experimental Area	L	2L
Morgantown	2800 lb. in the spring of 1930. In 1933, 1100 lb. were added to the plots that received no nitrogen. The amounts added to the plots that received nitrogen fertilizers were adjusted in accordance with the equivalent acidity or basicity of the fertilizer (6)	1700 lb. in the spring of 1930, and 3050 lb. in the spring of 1933
Moorefield	1300 lb. in the spring of 1930	2550 lb. in the spring of 1930
Aurora	2800 lb. in the spring of 1930	4650 lb. in the spring of 1930
Wardensville	1700 lb. in the spring of 1931	2950 lb. in the spring of 1931
Spencer	1500 lb. in the fall of 1934	2500 lb. in the fall of 1934
Palestine	1200 lb. in the fall of 1934	2000 lb. in the fall of 1934

[1]The limestone used at Morgantown, Moorefield, Aurora, and Wardensville had a calcium carbonate equivalent of 80%. On the experiments at Spencer and Palestine a by-product lime with a calcium carbonate equivalent of about 100% was used. In all experiments the lime was applied in amounts calculated to bring the surface three in. of soil to pH 6.0 and 6.5, respectively, for the L and 2L treatments.

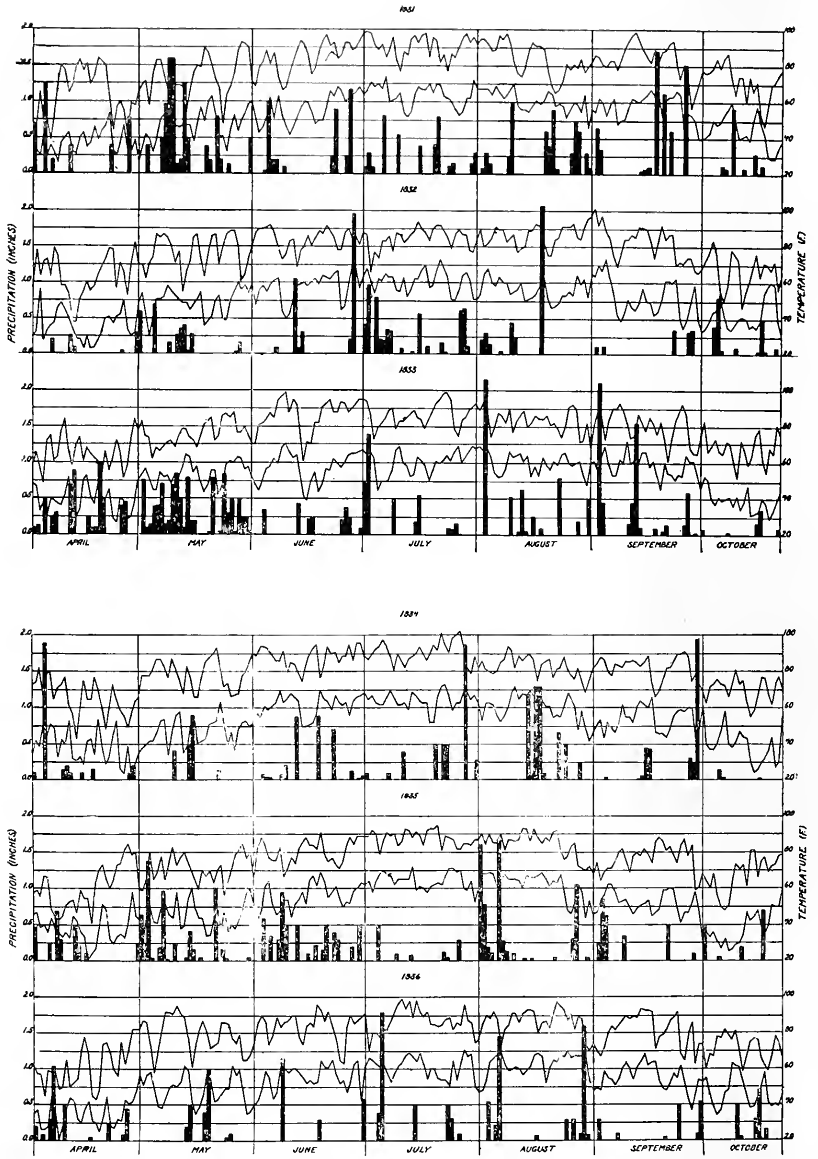


FIG. 1—Rainfall and temperature data for Morgantown area (1931-1936)*

*The rainfall data were obtained mostly from the Federal Weather Bureau station at Morgantown. Where the records at Morgantown are not complete the data were obtained from the nearby Fairmont station. The temperature data were obtained from the station at Clarksburg rather than at Morgantown because the records are more complete and the data obviously more trustworthy.

the Upshur clay soil at Spencer is severely eroded. As shown in the table, this area has only 1½ in. of topsoil. All of the soils are moderately to strongly acid and low to very low in available phosphorus as measured by Truog's method *(11)*. Three of the areas are very low in nitrogen and organic matter. The elevation of the experimental areas is approximately 1000 ft., except at Aurora, where it is 2500 ft., and at Spencer and Palestine, where it is about 700 ft.

The average annual precipitation for West Virginia is 43 in. At Aurora the precipitation is about 10 in. higher than the average for the state, whereas at Moorefield and Wardensville it is about 10 in. lower. The total rainfall during the six summer months (April to September) averages about 55 percent of the total for the year, and the months of greatest precipitation are usually June, July, and August. In spite of the higher rainfall the pastures are usually drier during July and August than at any other time during the year. This, of course, is due to the high temperatures, which result in rapid evaporation and transpiration.

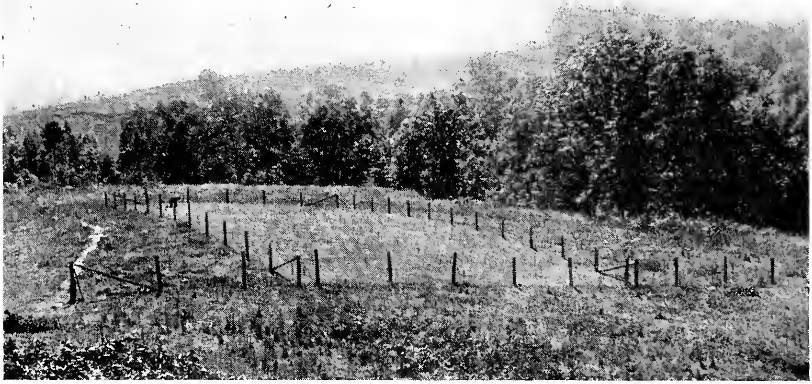


FIG. 2—Photograph of the Spencer plots, situated on a poor pasture area of Upshur clay

During the period in which these experiments were in progress, weather conditions were less favorable than normal. The summers of 1930, 1934, and 1936 were relatively dry and poor for pasture production. The seasons of 1932 and 1935 were fair, and only the seasons of 1931 and 1933 were very favorable. These facts should be considered when interpreting the results. Rainfall and temperature data for the Morgantown station for 1931-1936 inclusive are given in Figure 1.

Each of the experimental areas was divided into a number of 0.002 acre plots (7¼ x 12 ft.) which were separated by narrow alleys [Figure 2]. The important combinations of lime and fertilizers for the experiments started in 1930 and in 1932 are shown in Table 2, and those for the experiments started in 1934, in Table 3. The other treatments in-

TABLE 2—*Description of some of the important treatments of the four main experiments (Morgantown, Aurora, Moorefield, and Wardensville)*[1]

Treatment No.	Treatment designation	Description of treatment[3]
3, 8, 13	Check	None
10	2L	Lime
1	P	Superphosphate
2	P-2L	Superphosphate and lime
4	P-K	Superphosphate and muriate of potash
5	P-K-2L	Superphosphate, muriate of potash, and lime
6	N-P-K	Nitrate of soda, superphosphate, and muriate of potash
7	N-P-K-2L	Nitrate of soda, superphosphate, muriate of potash, and lime
9	N-P-K-L	Same as No. 7, except different amounts of lime
11	1/2N-P-K-2L	Same as No. 7, except one-half as much nitrate of soda
12	2N-P-K-2L	Same as No. 7, except twice as much nitrate of soda
14	2N-2P-K-2L	Same as No. 7, except twice as much nitrate of soda and superphosphate
15	N-2P-K-2L	Same as No. 7, except twice as much superphosphate

[1]Tables 5 and 15 give the additional treatments at Morgantown and Wardensville respectively; and Table 8 for the treatments at Maidsville.

[2]In the Morgantown experiment 2L was substituted for L in treatment No. 9, and L for 2L in the other plots receiving lime. See Table 4 for the amounts of lime used in the different experiments.

[3]Amounts used: (lb. per acre)
P = 500 lb. 20% superphosphate in first and third years of experiment.
2P = 500 lb. 20% superphosphate in each of first four years.
K = 100 lb. muriate of potash in first and third years.
1/2N = 100 lb. nitrate of soda in early spring.
N = 100 lb. nitrate of soda in early spring and in midsummer.
2N = 200 lb. nitrate of soda in early spring and in midsummer.

cluded in the Morgantown and Wardensville experiments and the special nitrogen treatments of the Maidsville experiment are shown in connection with the tables on yield and botanical composition. Table 4 (see page 5) shows the amounts of lime used in the various experiments. All treatments were in quadruplicate. Except for the area at Wardensville, which was plowed and reseeded, lime and fertilizer were applied as a topdressing without seed or cultural treatment.

Yields of forage were determined by clipping the plots with a lawnmower. The frequency of clipping depended upon the rate of growth, but ordinarily four to six clippings were made during a season. At Spencer and Palestine the herbage was clipped at a height of approximately one inch. The other areas were clipped at a height of 1¼ in. during the first three years; since then they have been clipped at a height of 2 in. The clipped herbage was dried at a temperature of approximately 150° F. and the yields expressed as pounds per acre of dry forage (about 1½% moisture). The clippings from certain selected plots were analyzed for calcium, phosphorus, and crude protein.

In addition to determining the yields and the chemical composition of the forage, estimates of the botanical composition of each plot were made usually twice each year, during June and September. These esti-

mates give the percentage of the total area occupied by bare space, weeds, legumes, desirable pasture grasses, and undesirable native grasses. Forty percent Kentucky bluegrass, for example, means 40 percent of a perfect stand of Kentucky bluegrass. Ten percent bare space means that the total vegetation makes up 90 percent of a perfect stand.

TABLE 3—*Description of fertilizer treatments of Spencer and Palestine experiments*[1]

Treatment No.	Treatment designation	Description of treatment[2]
3, 8	Check	None
1	P	Superphosphate
2	P-L	Superphosphate and lime
4	P-K	Superphosphate and muriate of potash
5	P-K-L	Superphosphate, muriate of potash, and lime
6	N-P-K	Sulfate of ammonia, superphosphate, and muriate of potash
7	N-P-K-L	Sulfate of ammonia, superphosphate, muriate of potash, and lime
9	N-P-K-2L	Same as No. 7, except for additional lime
10	L	Lime
12	N-P-L	Same as No. 7, except that muriate of potash is omitted
13	1/2P-L	Same as No. 2, except that amount of superphosphate is reduced
14	1/2P-1/2K-L	Same as No. 5, except that amounts of superphosphate and muriate of potash are reduced

[1]See Table 4 for amounts of lime used.
[2]Amounts of fertilizer used are as follows:
P = 500 lb. 20% superphosphate in fall of 1934.
1/2P = 300 lb. 20% superphosphate in fall of 1934.
K = 100 lb. muriate of potash in fall of 1934.
1/2K = 50 lb. muriate of potash in fall of 1934.
N = 100 lb. sulfate of ammonia each spring.

EFFECT OF LIME AND FERTILIZER ON THE BOTANICAL COMPOSITION OF PASTURES

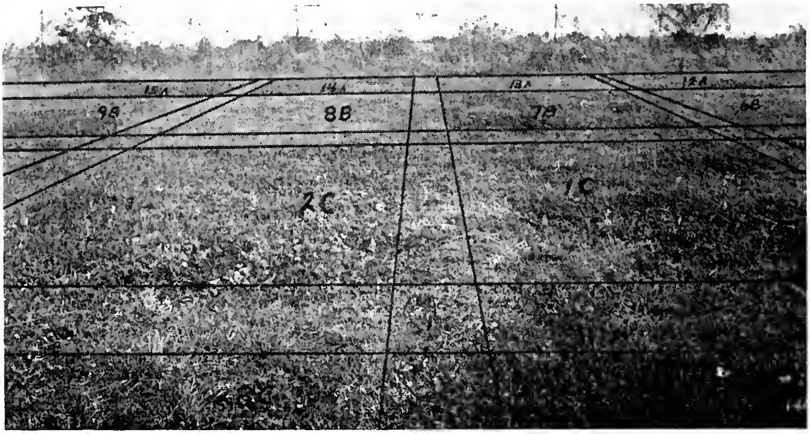
It has been found that under West Virginia conditions the botanical composition of a pasture is a good measure of its productivity *(7)*. If the soil is fertile Kentucky bluegrass (*Poa pratensis*) and white clover (*Trifolium repens*) are the dominant species unless of course the pasture has been grossly mismanaged. Other desirable plant species found in West Virginia pastures are: red top (*Agrostis alba*), timothy (*Phleum pratense*), Canada bluegrass (*Poa compressa*), orchard grass (*Dactylis glomerata*), hop clover (*Trifolium spp.*), and common lespedeza (*Lespedeza striata*).

Pastures consisting mostly of these plant species produce not only a greater amount of herbage per acre than does the poor type of pastures, which contain mostly poverty grass, broomsedge, and weeds; they also produce herbage of better quality. For these reasons it is evident that one of the most practical methods of determining the value of lime and fertilizers on permanent pastures is to determine the effect of such treatments on the botanical composition of the sod.

At the time the experiment was started, this area was estimated to contain 58 percent native grasses, largely poverty grass with small percentage of broomsedge; 19 percent weeds, predominantly cinquefoil, yarrow, everlasting, and English plantain; 7 percent bare space; 2 percent white and red clovers; and 14 percent Kentucky bluegrass and red top. The small percentage of desirable grasses and legumes in this pasture is not surprising because, as shown in Table 1, the soil is strongly acid and very low in available phosphorus.

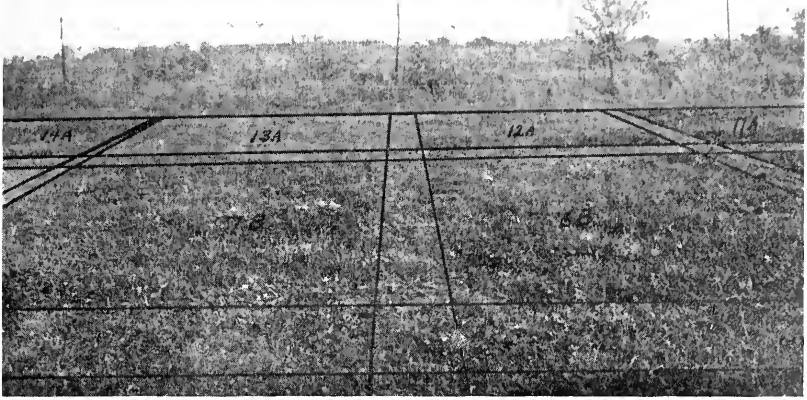
It is evident from Figures 3a and 3b that the lime and fertilizer treatment resulted in a very good sod of Kentucky bluegrass and white clover. White clover came in much sooner than did Kentucky bluegrass, but, as would be expected, it showed marked seasonal variations. The largest amounts were present during 1932 and 1933, although there were also considerable amounts in the late fall of 1931 and the early spring of 1934 on the well-treated plots. The botanical estimates for the P-K-L treatment showed 15 percent clover in 1931 and 35 percent in the fall of 1933. There were only negligible amounts of white clover in 1930 and 1936 and also during most of 1935. Undoubtedly the small percentage of clover on the area during the last few years was due partly to the unfavorable seasons, 1934 and 1936 being especially dry.

The rate at which the percentage of Kentucky bluegrass increased as a result of lime and fertilizer treatments is shown in Figure 4. It is interesting to note that before clover became an important factor, the P-K-L treatment produced no increase in the percentage of Kentucky bluegrass. Nitrogen fertilizers, in addition to P-K-L, however, mate-



15A—N-2P-K-L 14A—2N-2P-K-L 13A—None 12A—2N-P-K-L
9B—N-P-K-2L 8B—None 7B—N-P-K-L 6B—N-P-K
2C—P-L 1C—P
28C—None 27C—N-P-K-L

FIG. 3A—Some of the plots on the Dekalb soil at Morgantown, October 9, 1933



14A—2N-2P-K-L 13A—None 12A—2N-P-K-L 11A—1/2N-P-K-L
7B—N-P-K-L 6B—N-P-K

FIG. 3B—Some of the plots on the Dekalb soil at Morgantown, October 9, 1933

rially increased the percentage of Kentucky bluegrass during the first year. Following the appearance of large amounts of clover in the fall of 1931 and 1932 there were rapid increases in the percentage of bluegrass; and during the last few years, when the seasons were unfavorable and the amounts of clover very small, marked decreases in the percentage of Kentucky bluegrass were noted, especially on the plots receiving

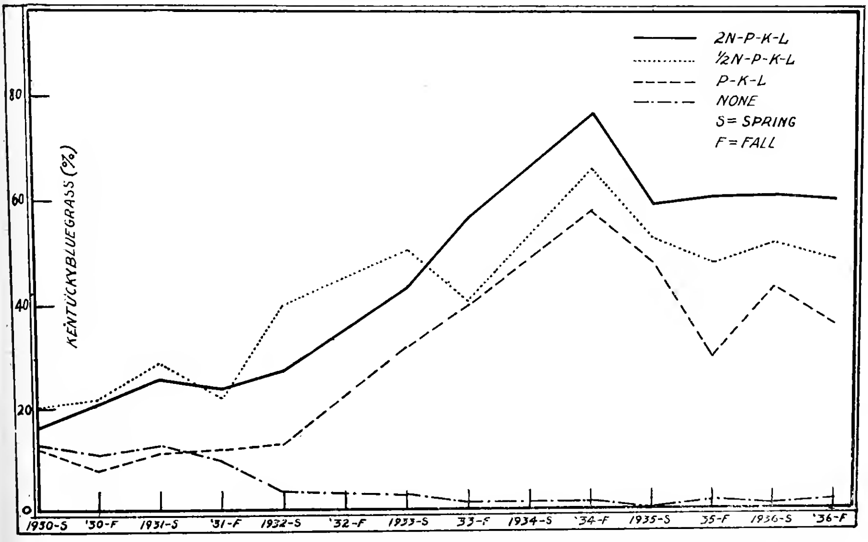


FIG. 4. ESTIMATED PERCENTAGES OF KENTUCKY BLUEGRASS [INCLUDES ALSO A SMALL PERCENTAGE OF RED TOP] ON CERTAIN PLOTS ON THE DEKALB SILT LOAM AT MORGANTOWN.

TABLE 5—*Average estimated botanical composition of the plots on the Dekalb silt loam at Morgantown*[1]

Plot No.	Treatment[2]	Average 1932-1936					September 1936
		Bare space	Weeds[3]	Undesirable grasses[4]	White clover[5] (*Trifolium repens*)	Kentucky bluegrass (*Poa pratensis*)	Kentucky bluegrass (*Poa pratensis*)[6]
		%	%	%	%	%	%
3, 8, 13, 18, 23, 28	None	14	33	49	1	3	4
1	P	10	20	58	4	8	10
2	P-L	8	18	31	9	34	33
4	P-K	11	24	53	4	8	10
5	P-K-L	6	16	28	11	39	39
6	N-P-K	6	17	52	5	20	24
7	N-P-K-L	4	14	24	8	49	61
9	N-P-K-2L	5	15	27	7	46	61
10	L	10	27	53	4	6	8
11	1/2N-P-K-L	5	16	15	12	52	53
12	2N-P-K-L	4	15	18	7	56	62
14	2N-2P-K-L	3	12	10	6	69	71
15	N-2P-K-L	3	14	14	10	59	68
16	Ammo-phos-K	8	20	63	1	8	11
17	Ammo-phos-K-L	4	14	22	9	51	61
19	N-P-K (Sulfate of Ammonia)	9	16	67	1	7	12
20	N-P-K-L (Sulfate of Ammonia)	4	15	22	7	52	58
21	N-P-K (Calnitro)	7	15	61	4	13	15
22	N-P-K-L (Calnitro)	5	12	28	9	46	57
24	N-P-K (Urea)	6	16	53	4	21	22
25	N-P-K-L (Urea)	5	12	25	8	50	58

[1]Every plot number is in quadruplicate, and the values reported are the average of eight estimates for each of the four plots.

[2]The Ammo-phos (plots 16 and 17) was applied annually in amounts equivalent to 250 lb. 20% superphosphate and 200 lb. of nitrate of soda. Treatments 19 to 25 differed from 6 and 7 only in the source of nitrogen.

[3]Predominantly yarrow (*Achillea millefolium*), cinquefoil (*Potentilla sp.*), everlasting (*Antennaria sp.*), and English plantain (*Plantago lanceolata*). Cinquefoil and everlasting were crowded out on the plots that were limed and fertilized.

[4]Poverty grass (*Danthonia spicata*) with smaller amounts of broomsedge (*Andropogon virginicus*).

[5]Includes small percentages of red clover (*Trifolium pratense*).

[6]Includes small percentages of red top (*Agrostis alba*).

no nitrogen fertilizer. It should be recognized, however, that the effect of the absence of clover on the percentage of bluegrass would show up much more quickly on these plots than on grazed plots since the latter receive a considerable amount of nitrogen from manure.

The average values of eight botanical estimates during the period 1932-1936 are summarized in Table 5. (The first two years were omitted in this summary table because the differences between the various treatments were still relatively small.) The untreated plots averaged only 4 percent total desirable species during this period. Lime alone or superphosphate alone had relatively little effect on the percentage of total desirable species. A combination of lime and superphosphate, however, produced a marked change in the botanical composition of the pasture in that Kentucky bluegrass and white clover replaced a large percentage of the weeds and undesirable grasses. The average percentage of total desirable species for the P-L treatment was 43. Potash and nitrogen fertilizers, in addition to lime and superphosphate, gave additional increases in the percentage of total desirable species, the totals for the P-K-L, 1/2N-P-K-L, N-P-K-L, 2N-P-K-L, and 2N-2P-K-L treatments being 50, 64, 57, 63, and 75 percent, respectively. Except when used in small amounts, however, nitrogen fertilizer decreased the percentage of clover.

On the limed plots receiving different nitrogen fertilizers, no significant difference was noted in the percentage of total desirable species. On the unlimed plots, however, there were very marked differences. The plots receiving non-acid-forming carriers of nitrogen (Calnitro and nitrate of soda) averaged 21 percent total desirable species as compared with only 8 percent for those receiving strongly acid-forming carriers (sulphate of ammonia and Ammo-phos). The plots that received urea, which is only slightly acid-forming, averaged 25 percent total desirable species.

The percentages of Kentucky bluegrass as estimated in the fall of 1936 are also shown in Table 5 for comparison with the average for 1932-1936. Very little difference is seen between the two sets of values. This should not be taken to mean that there has been no change in botanical composition, since as shown in Figure 3, the percentage values for bluegrass increased to a maximum in 1934 and then decreased slightly. The results do show, however, that the effect of the lime and fertilizer treatments is still very apparent even where no treatment has been given for 4½ years.

Aurora Experiment

The average values for the estimated botanical composition of the plots at Aurora during the period 1931-1936 are given in Table 6. Superphosphate alone reduced the bare space from 24 to 9 percent and increased the amount of desirable grasses and clover from 7 to 32 percent. Moreover, the very heavy superphosphate treatment was somewhat more effective than the normal application. This marked response

TABLE 6—*Average estimated botanical composition of the plots on the Upshur clay loam at Aurora*[1]

Plot No.	Treatment	Average 1931-1936					Desirable grasses Sept. 1936
		Bare space	Weeds[2]	Poverty grass (*Danthonia spicata*)	White clover (*Trifolium repens*)	Desirable grasses[3]	
		%	%	%	%	%	%
3, 8, 13	None	24	18	51	1	6	2
1	P	9	23	36	11	21	12
2	P-2L	13	20	30	14	23	14
4	P-K	11	19	39	9	22	10
5	P-K-2L	10	20	34	13	23	20
6	N-P-K	9	25	27	9	30	24
7	N-P-K-2L	7	25	17	10	41	34
9	N-P-K-L	7	21	21	11	10	35
10	2L	21	20	47	3	9	5
11	1/2N-P-K-2L	7	24	19	15	35	20
12	2N-P-K-2L	9	21	19	8	43	38
14	2N-2P-K-2L	7	19	13	10	51	53
15	N-2P-K-2L	7	22	16	14	41	39

[1]Every plot number is in quadruplicate, and the values reported are the average of nine estimates for each of the four plots.

[2]Predominantly English plantain (*Plantago lanceolata*), oxeye daisy (*Chrysanthemum leucanthemum*), wild carrot (*Daucus carota*), and yarrow (*Achillea millefolium*).

[3]Predominantly Kentucky bluegrass (*Poa pratensis*), red top (*Agrostis alba*) and other bent grasses, and Canada bluegrass (*Poa compressa*).

Table 7—*Average estimated botanical composition of the plots on the Huntington silt loam at Moorefield*[1]

Plot No.	Treatment	Average 1930-1935					October, 1935
		Bare space	Weeds[2]	Undesirable grasses[3]	White clover (*Trifolium repens*)[4]	Kentucky bluegrass (*Poa pratensis*)	Kentucky bluegrass (*Poa pratensis*)
		%	%	%	%	%	%
3, 8, 13	None	5	9	9	4	73	62
1	P	4	7	8	5	76	67
2	P-2L	4	7	8	6	75	70
4	P-K	4	8	7	6	75	67
5	P-K-2L	4	7	5	6	78	73
6	N-P-K	4	7	5	4	80	73
7	N-P-K-2L	4	8	6	4	78	67
9	N-P-K-L	4	8	4	3	81	70
10	2L	4	8	7	5	76	72
11	1/2N-P-K-2L	4	8	5	5	78	71
12	2N-P-K-2L	4	6	4	2	84	76
14	2N-2P-K-2L	3	5	3	2	87	85
15	N-2P-K-2L	3	6	6	4	81	70

[1]Every plot number is in quadruplicate, and the values reported are the average of seven estimates for each of the four plots.

[2]Predominantly English plantain (*Plantago lanceolata*), wood sorrel (*Oxalis sp.*) dandelion (*Taraxacum officinale*), and yarrow (*Achillea millefolium*).

[3]Crab grass (*Digitaria sanguinalis*), foxtail (*Setaria sp.*), and false red top (*Tridens flavus*).

[4]Includes small amounts of hop clover (*Trifolium agrarium*).

to superphosphate is to be expected because, as shown in Table 1, the soil is very low in readily available phosphorus. Lime produced only a small increase in the percentage of desirable species in spite of the fact that the soil has a pH value of 5.4. Potash had no apparent effect on the botanical composition. Heavy applications of nitrogen fertilizer produced a marked increase in the percentage of desirable grasses but decreased the percentage of clover. The light application of nitrogen, on the other hand, produced a marked increase in the percentage of desirable grasses without decreasing the percentage of white clover. The average percentage of desirable grasses and legumes for the P-K-2L, 1/2N-P-K-2L, N-P-K-2L, and 2N-P-K-2L treatments was 36, 50, 51, and 51, respectively. The 2N-2P-K-2L treatment increased the total desirable species to 61 percent. Except on the plots receiving heavy applications of fertilizer, the percentage of desirable grasses was somewhat lower in 1936 than the average for the period 1931-1936.

As on the Dekalb soil at Morgantown, white clover was much more abundant in 1932 and 1933 than during the other years. There was also a fairly good stand of clover on the treated plots in the fall of 1931, in the early spring of 1934, and during part of 1935. In 1930 and 1936 the amounts of white clover were negligible.

Moorefield Experiment

There was a good sod of Kentucky bluegrass even on the untreated plots on the Huntington silt loam at Moorefield (Table 7). This indicates that neither soil acidity nor soil fertility was an important limiting factor. As shown in Table 1, the untreated soil has a pH value of 5.8 and has 21 pounds of readily available phosphorus per two million pounds of the 0-3 in. layer. It is not surprising, therefore, that lime and fertilizer had relatively little effect on the average botanical composition. The unfertilized plots averaged 77 percent desirable grasses and legumes as compared with 89 percent for the very heavily fertilized plots. There was very little clover except in the fall of 1932, during the very favorable year of 1933, and in the early spring of 1934. For this reason the average values given in Table 7 appear low and do not adequately show the differences resulting from some of the treatments. For example, the percentage of clover during 1933 for some of the more important plots averaged as follows: untreated, 11 percent; 2L, 22 percent; P, 22 percent; P-2L, 30 percent; P-K-2L, 30 percent; 1/2N-P-K-L, 23 percent; N-P-K-2L, 13 percent; and 2N-P-K-L, 7 percent. These results show that on a good sod of Kentucky bluegrass even light applications of nitrogen fertilizer may produce a marked decrease in the percentage of clover.

Maidsville Experiment

The Westmoreland soil of this experiment was neither as strongly acid nor as low in available phosphorus as the soils of most of the other areas, and there was a fairly good sod of Kentucky bluegrass at the

TABLE 8—*Average estimated botanical composition of the plots on the Westmoreland silt loam at Maidsville*[1]

Plot No.	Treatment[2]	Average 1931-1936					Sept. 1936
		Bare space	Weeds[3]	Poverty grass (*Danthonia spicata*)	White clover (*Trifolium repens*)	Kentucky bluegrass[4] (*Poa pratensis*)	Kentucky bluegrass (*Poa pratensis*)
		%	%	%	%	%	%
1, 4, 10, 16	None	10	16	50	4	20	6
2	P	6	15	47	6	26	11
3	P-K	8	15	45	6	26	12
5	N-P (Mar. 100, June 100)	5	14	27	7	47	35
6	N-P-K (March 200)	6	14	26	6	48	28
7, 13	N-P-K (Mar. 100, June 100)	6	14	30	6	44	38
8	N-P-K (Mar. 100, July 100)	6	14	31	7	42	33
9	N-P-K (Mar. 100, June 50, Aug. 50)	5	14	23	8	50	44
11	N-P-K (Mar. 50, June 100, Aug. 50)	6	16	24	8	46	37
12	N-P-K (Mar. 50, June 50, July 50, Aug. 50)	6	14	22	8	50	40
14	1/2N-P-K (Mar. 100)	7	17	35	7	34	16
15	1/2N-P-K (Mar. 50, June 50)	7	17	27	9	40	26
17	1/2N-P-K (June 100)	6	14	36	8	36	27
18	1/2N-P-K (June 50, Aug. 50)	6	14	24	9	47	39

[1]Every plot number is in quadruplicate and the values reported are the average of eight estimates for each of the four plots.

[2]The distribution of the nitrate of soda is indicated in parentheses. Thus (Mar. 100) means 100 pounds per acre of nitrate of soda in March. P and K have the same meaning as described in Table 2.

[3]Predominantly yarrow (*Achillea millefolium*), and English plantain (*Plantago lanceolata*).

[4]Includes also a very small amount of other desirable grasses, mostly orchard grass (*Dactylis glomerata*).

time the experiment was started. The experiment was planned primarily to study the effect of applying nitrogen fertilizer at different times during the year on the increases in yield throughout the season. Most of the results of this experiment will be reported in detail in another publication, but some of the results are of interest here.

The average botanical composition of the various plots for the period 1931-1936 is given in Table 8. The percentage of total desirable species has averaged 24, 32, 47, and 53, respectively, for the untreated, P-K, 1/2N-P-K, and N-P-K treatments. Of particular interest, however, are the estimates of Kentucky bluegrass in the fall of 1936 (last column of Table 8). The percentage values at that time were directly related to the rate of nitrogen fertilization, being 37, 27, and 12, respectively, for the N, 1/2N, and no N treatments. These differences emphasize the importance of an adequate supply of available nitrogen in order to maintain a sod of Kentucky bluegrass. When clovers or other legumes are plentiful they supply nitrogen for the growth of bluegrass, but following a series of years unfavorable for clover, available nitrogen becomes an important limiting factor, especially on clipped plots. It should be recognized, however, that under grazing conditions a large percentage of the nitrogen that is removed in the grass is returned to the pasture in the droppings. Thus the decrease in the percentage of bluegrass in this experiment no doubt was greater than would be expected under grazing.

Wardensville Experiment

As was stated earlier, the experiment on the Monongahela fine sandy loam at Wardensville differed from the others in that the area was plowed and reseeded. The initial application of lime and fertilizer was made in the spring of 1931 and disked into the soil. The area was then seeded with a mixture of Kentucky bluegrass, red top, and white clover, using a nurse crop of oats. The oats were harvested early, and later in the season the weeds were cut, but the grass and clover were not clipped until the following spring.

In spite of the high acidity of the soil (pH 4.9) on the plots receiving neither lime nor fertilizer, estimates made in the spring of 1932 show a fairly good stand of red top, white clover, and Kentucky bluegrass. The stand of bluegrass and clover was considerably better, however, on the plots receiving lime and superphosphate. Neither nitrogen nor potash fertilizers had any apparent effect on the total percentage of desirable species, but, as might be expected, nitrogen fertilizers produced a marked reduction in the percentage of white clover. On the limed plots there was no significant difference between the effect of different nitrogen carriers, but on the unlimed plots there were much smaller amounts of clover where the acid-forming carriers of nitrogen were used (Table 9). The increase in clover from liming averaged 21 percent for the non-acid-forming carriers of nitrogen (Calnitro and nitrate of soda) as compared with 79 percent for the acid-forming carriers (sulphate of ammonia, urea, and Ammo-phos).

TABLE 9—*Effect of acid-forming and non-acid-forming nitrogen fertilizers on the estimated percentages of white clover on the Monongahela fine sandy loam at Wardensville, June 1932*

Nitrogen sources	Fertilizer treatment	Percentage of white clover		% increase in white clover from liming
		Unlimed plots	Limed plots	
......	P and P-K	33	43	30
Non-acid-forming	N-P-K (nitrate of soda)	21	26	24
	N-P-K (calnitro)	26	31	19
Acid-forming	N-P-K (sulfate of ammonia)	15	28	87
	N-P-K (urea)	16	29	81
	N-P-K (Ammo-phos)[1]	10	17	70

[1]The relatively small percentage of clover on these plots undoubtedly resulted from applying all the nitrogen in the spring (Table 5, second footnote).

All the clover was killed by the very dry summer of 1932, and it was just beginning to come back when it was killed during the hot, dry summer of 1934. In fact, the plots were so severely injured by moles and dry weather during 1934 that the experiment was temporarily discontinued. The botanical estimates made early in 1934 emphasize the importance of lime and fertilizers in determining the botanical composition of a pasture (Table 10). It will be noted first that, although all plots had received the same seed treatment in 1931, the limed plots were predominantly Kentucky bluegrass in 1934, whereas the unlimed plots were predominantly red top. There was still a good stand of Kentucky bluegrass in 1934 on the plots that received lime but no superphosphate, indicating that the soil contained enough readily available phosphorus to support a stand of Kentucky bluegrass for the first few years after seeding. It should be recognized, however, that the plots were seeded during an unusually favorable year and that equilibrium between the soil and the vegetation had not yet been fully established.

As at Morgantown, the residual effect of the nitrogen fertilizers was very evident on the unlimed plots. Those that received neutral or basic

TABLE 10—*Effect of soil acidity on the percentage of Kentucky bluegrass and red top on the Monongahela fine sandy loam at Wardensville, Spring 1934*

Treatment	Unlimed		Limed	
	Ky. bluegrass (*Poa pratensis*)	Red top (*Agrostis alba*)	Ky. bluegrass (*Poa pratensis*)	Red top (*Agrostis alba*)
None	16	57	60	14
P and P-K	19	58	62	12
N-P-K (Non-acid carriers of nitrogen)	37	46	67	11
N-P-K (acid-forming carriers of nitrogen)	16	65	64	16

carriers of nitrogen averaged 37 percent Kentucky bluegrass and 46 percent red top as compared with 16 percent Kentucky bluegrass and 65 percent red top for the plots receiving acid-forming carriers of nitrogen (Table 10).

Spencer Experiment

The soil used for the Spencer experiment was very unproductive, and at the time the experiment was started (fall 1934), the estimates showed a total of only 1 percent Kentucky bluegrass and white clover. The remaining 99 percent was composed of native grasses, weeds, and bare space.

TABLE 11—*Estimates of the percentage of white clover, hop clover, and Kentucky bluegrass one to 2½ years after treatment on the Upshur clay at Spencer*

Treatment of plots represented[1]	1935 (Oct. 9)		1936 (May 19)		1937 (June 22)	
	White clover	Kentucky bluegrass	White clover	Kentucky bluegrass	Hop clover	Kentucky bluegrass
	%	%	%	%	%	%
None	4	2	3	3	19	4
L	11	2	15	3	17	8
P, P-K	5	4	7	5	21	7
P-L, 1/2P-L, P-K-L, 1/2P-1/2K-L	15	3	25	4	34	12
N-P-L, N-P-K-L, N-P-K-2L	16	7	27	9	22	20

[1]See Tables 3 and 4 for more detailed treatments. Since there was no increase in yield or percentage of desirable species from K, no greater increase from P than from 1/2P and no apparent difference between the effect of L and 2L, a number of the treatments were grouped together in the above table.

As in most of the other experiments, the effect of the treatments was first evidenced by the increase in the percentage of white clover (Table 11). Within one year after treatment the limed plots had nearly three times as much white clover as the untreated plots. When used without lime, phosphorus and potash had little effect on the percentage of white clover, but the combination of lime and phosphorus, with or without potash or nitrogen, increased the percentage of clover to approximately four times that of the untreated plots. During 1936 the differences were even greater, the plots receiving phosphorus and lime averaging about 25 percent clover as compared with 3 percent for the untreated plots. Most of the white clover died during the extremely dry summer of 1936. In the early summer of 1937, hop clover was present in large amounts. As shown in Table 11, even the untreated plots had an average of 19 percent hop clover. This indicates that hop clover can grow on a relatively poor soil. It will be noted, however, that although lime alone or superphosphate alone had little effect on the abundance of hop clover, the combination of lime and phosphorus nearly doubled the amount present.

Kentucky bluegrass was rather slow in spreading. This is not surprising when it is considered that there was less than one percent when the experiment was started. Nitrogen fertilizers definitely increased the percentage of bluegrass. The total percentage of bluegrass in June 1937 was 4 percent for the untreated plots, 12 percent for the plots receiving phosphorus and lime, and 20 percent for those receiving nitrogen in addition to phosphorus and lime. No doubt more bluegrass will spread in the P-L plots as greater amounts of nitrogen become available from the legumes present.

Palestine Experiment

The untreated soil on the Palestine experiment appeared to be the least productive of any of the experimental areas, being very low in available phosphorus (Table 1). Nevertheless, even the untreated plots supported a good stand of common lespedeza, a species that apparently can grow on very unproductive soils. Fertilizers gave marked increases in yield during the first year (as will be shown in Table 19), but the change in the percentage stand of lespedeza was relatively small. As shown in Table 12, large amounts of lespedeza were still present in June 1937, in spite of the fact that the plots had been clipped closely for over two years. Lime had no effect on the percentage of lespedeza, whereas the plots receiving phosphorus alone or phosphorus and lime showed somewhat higher percentages of lespedeza than the untreated plots.

Table 12—*Estimates of common lespedeza and of white clover on Holston silt loam at Palestine as affected by fertilization and liming*

Treatment of plots represented[1]	Percentage of common lespedeza		Percentage of white clover
	1935 (Sept. 6)	1937 (June 22)	1936 (May 18)
None	52	46	1
L	56	41	1
P, P-K	60	56	18
P-L, P-K-L	56	59	21
1/2P-L, 1/2P-K-L	59	64	13
N-P-L, N-P-K-L, N-P-K-2L	62	58	18

[1]See Tables 3 and 4 for detailed treatments. Since there was no increase in yield or percentage of desirable species from K, and no consistent difference between L and 2L, a number of the treatments were grouped together in the above table.

There appeared to be no Kentucky bluegrass or white clover on the area when the experiment was started, and in the spring of 1937 (2½ yr. after treatment) the estimates showed only 2 or 3 percent of Kentucky bluegrass on the treated plots. Since a few scattered plants of bluegrass have become established this species should, of course, spread rapidly on the treated plots. White clover, although more plentiful than Kentucky bluegrass, has made up only a very small percentage stand even on the treated plots except during the early part of the 1936 season. In May 1936 it will be noted (Table 12) that there was approx-

imately 18 percent white clover on the phosphorus plots. Lime had no significant effect on the percentage of white clover and, as will be seen in Table 19, no effect on yields.

RELATION BETWEEN THE CHEMICAL PROPERTIES OF THE SOIL AND THE RESPONSE OF WHITE CLOVER TO LIME AND SUPERPHOSPHATE

It has been shown in Tables 5 to 12, inclusive, that the treatment of the different pasture areas with lime and fertilizer in most cases has brought about marked decreases in the percentage of weeds and poor native grasses in the turf and an increase in the percentage of desirable species, particularly Kentucky bluegrass and white clover. The changes that have taken place, however, have varied with the soil and with the treatment. In general, the use of superphosphate and lime has brought about the most marked improvement in the type of vegetation. This does not mean that the pasture soils are well supplied with available nitrogen; many of them are just as deficient in nitrogen as in phosphorus and lime. This was well illustrated by the fact that when legumes were

TABLE 13—*Increase in percentage of white clover from use of lime and superphosphate, as related to acidity and readily available phosphorus content of the soils*

Location of experiment	Soil type	Available P	pH	Increase in % white clover[1]	
				From superphosphate	From lime
Morgantown	Dekalb silt loam	10	5.0	20	22
Aurora	Upshur clay loam	9	5.4	29	9
Moorefield	Huntington silt l.	21	5.8	8	4
Spencer	Upshur clay	9	4.9	12	20
Palestine	Holston silt loam	<5	5.3	21	3

[1]Increases from superphosphate obtained by comparing the L and P-L treatments; increases from lime, by comparing the P and P-L and the P-K and P-K-L plots.

The percentage of white clover in the P-L plots for the different areas were as follows: Morgantown, 34; Aurora, 35; Moorefield, 30; Spencer, 27; and Palestine, 22. Estimates at the first three locations are for 1933, and at the last two locations for 1936.

not present, marked increases in the percentage of Kentucky bluegrass were obtained by use of nitrogen. By use of phosphorus and lime, however, white clover and other legumes are encouraged, and these legumes can supply at least a part of the nitrogen needed by the Kentucky bluegrass and other grasses. It is therefore of considerable practical interest to know to what extent the differences in the responses of white clover to treatments of lime and superphosphate on the different soils can be explained by differences in the pH and available phosphorus content of the soil.

As previously mentioned, 1933 was a good year for clover on the plots that had been established in 1930, and the early season of 1936 was favorable to clover on the plots established in 1934. The increase in clover resulting from the use of superphosphate and lime for those years is shown in Table 13. Although the use of superphosphate on

limed plots increased the amount of clover in the vegetation on all soils, it will be noted that the Huntington silt loam, which was considerably higher in available phosphorus than the other soils, showed the least response to superphosphate. The other four soils are very low in available phosphorus, and the increase in the percentage of white clover in three of the four cases is over 20 percent. This increase is particularly striking on the Holston silt loam at Palestine, where the L plots averaged only one percent white clover and the P-L plots 22 percent. Lime when used on plots receiving superphosphate increased the percentage of clover in the vegetation from 12 to 34 percent on the Dekalb silt loam and from 7 to 27 percent on the Upshur clay. These two soils, as will be noted, are the most acid of the group. The other three soils showed an increase of 3 to 9 percent in the percentage of clover from the use of lime. It would appear from these data that, although white clover still responds to lime on these soils at pH values of 5.4 to 5.8, the response is much smaller than on soils of lower pH value. Moreover, it would appear that at least 20 pounds of available phosphorus per two million pounds of the surface three in. of soil are necessary for the optimum amounts of white clover in the herbage. This is in general agreement with results obtained in other investigations in West Virginia *(7)*.

EFFECT OF LIME AND FERTILIZER ON THE YIELDS OF FORAGE

Relation of White Clover to Increases in Yields

The importance of white clover in determining the increases in yield of forage from fertilizer and lime treatments is illustrated in Figure 5. This figure shows the response to P-K-L and N-P-K-L during two consecutive years at Moorefield and at Wardensville, two areas of similar rainfall and other climatic conditions. As was explained previously, clover was abundant at Wardensville in 1932 and absent in 1933, whereas at Moorefield clover was present in only small amounts in 1932 but abundant in 1933. Thus at both Moorefield and Wardensville the response to lime and fertilizer, during a year when clover was absent, can be compared with the response on the same plots during a year when clover was abundant. Moreover, by comparing the response at Wardensville with the response at Moorefield during the same year, it is possible largely to eliminate the effect of seasonal differences. As an average for the two experiments, the P-K-L treatment increased the yield 25 percent when clover was absent and 85 percent when clover was abundant, whereas nitrogen fertilization in addition to P-K-L increased the yield 46 percent when clover was absent but only 4 percent when clover was abundant.

In considering the following yield data, therefore, it should be recognized that the differences in response obtained from year to year are the result not only of differences in weather conditions and time since the treatments were applied, but also of differences in the abundance of white clover.

The yields of dry herbage from the various lime and fertilizer treatments on the Dekalb silt loam at Morgantown are summarized in Table 14. Since the soil selected for this experiment is strongly acid and very low in available phosphorus (Table 1), it is not surprising that neither lime alone nor superphosphate alone gave satisfactory increases in yields. Potash gave marked increases in yield on the limed plots but had no apparent effect on the yield of the unlimed plots. The average increases from L, P, P-L, and P-K-L were 19, 36, 64, and 99 percent, respectively. The very heavy applications of superphosphate thus far have given only slightly higher yields than the moderate applications,

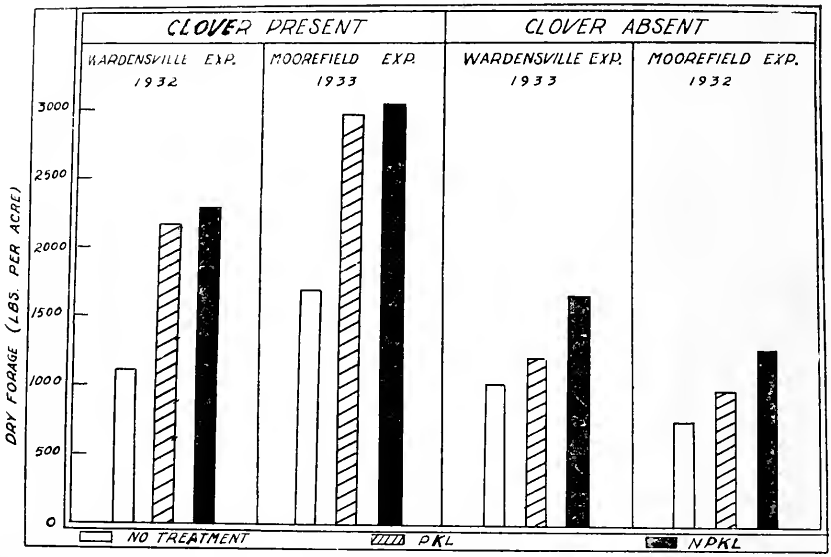


FIG. 5. THE EFFECT OF THE PRESENCE OF WHITE CLOVER ON THE RESPONSE OBTAINED WITH LIME AND DIFFERENT FERTILIZERS.

but the effect will undoubtedly last longer. Nitrogen fertilizers, especially when used in large amounts, produced marked increases in yields. A comparison of the increases in yields from nitrate of soda, sulphate of ammonia, Calnitro, and urea shows that on the limed plots no single nitrogen carrier has given consistently higher yields than the others, although during single years there have been differences. On the unlimed plots, sulphate of ammonia gave considerably lower yields after the first few years. Undoubtedly this difference was due to the residual acidic effect of the sulphate of ammonia.

In order to determine the response to any one fertilizer element, it is necessary first to supply all other limiting elements. The response to nitrogen fertilizers, for example, must be determined by comparing the yields of the P-K-L plots with the yields of the N-P-K-L plots, be-

Table 14—*Yields of forage from the various fertilizer and lime treatments on the Dekalb silt loam at Morgantown*

Plot No	Treatment[1]	Dry forage (Lb. per acre) 1930	1931	1932	1933	1934	1935	1936	Average	Average Increase (%)
3, 8, 13, 18, 23, 28	None	763	894	788	435	429	493	473	611	...
1	.	924	1104	1003	741	544	823	663	829	36
2	P-L	837	1254	1395	1386	615	935	604	1064	64
4	P-K	925	1191	960	526	460	667	510	748	22
5	P-K-L	922	1771	1708	1771	754	1037	562	1218	99
6	N-P-K	1223	1727	1363	1134	826	1103	824	1171	92
7	N-P-K-L	1234	2243	1747	1889	977	1261	746	1442	136
9	N-P-K-2L	1196	1967	1543	1865	901	1186	769	1347	120
10	L	828	1038	901	580	525	678	531	726	19
11	1/2N-P-K-L	1002	1924	1903	2179	995	1097	642	1392	128
12	2N-P-K-L	1308	2472	1935	2519	1233	1235	925	1661	172
14	2N-2P-K-L	1305	2617	1916	2535	1570	1412	958	1759	188
15	N-2P-K-L	1085	2421	1941	2283	1151	1352	807	1577	158
16	Ammo-phos-K	1063	1840	1346	923	825	1002	960	1137	86
17	Ammo-phos-K-L	1014	1879	1700	1859	1130	1236	976	1399	129
19	N-P-K (Sulfate of ammonia)	1066	1880	1251	742	662	891	784	1039	70
20	N-P-K-L (Sulfate of ammonia)	968	1860	1671	1753	906	1205	919	1326	117
21	N-P-K (Calnitro)	1036	1878	1381	1045	724	1074	1012	1164	91
22	N-P-K-L (Calnitro)	900	2088	1638	1737	840	1198	990	1342	120
24	N-P-K (Urea)	1136	1949	1414	1095	813	1096	898	1200	96
25	N-P-K-L (Urea)	1034	2067	1818	1973	958	1152	901	1415	132

[1]See Tables 2 and 4 for more detailed description of treatments.

[2]The Ammo-phos (plots 16 and 17) was applied annually in amounts equivalent to 250 lb. 20% superphosphate and 200 lb. of nitrate of soda. Treatments 17 to 25 differed from 6 and 7 only in the source of nitrogen.

cause P, K, and L are all limiting factors on this soil. The increase in yield determined in this manner for the various fertilizer elements is shown in Figure 6. The response to phosphorus, however, is underestimated because it could be determined only on plots that had not received potash. During the first year of the experiment the season was very unfavorable because of the dry summer and fall, and consequently lime, superphosphate, and potash, all of which penetrate very slowly when applied as a topdressing, gave relatively little increases in yield; in fact, lime produced a slight decrease in yield during the first year on most of the plots.

During 1931 to 1933, with favorable seasons and rapid increases in the percentages of Kentucky bluegrass and white clover on the plots receiving both lime and superphosphate, there were large increases in yield from lime, superphosphate, and potash. It is interesting to note, however, that lime in addition to N-P-K gave smaller increases in yield than lime in addition to P-K. Apparently this difference can be attributed at least partly to differences in the botanical composition of the plots. There was but little clover on any of the unlimed plots, but on the P-K-L plots clover accounted for a considerable portion of the total yield. Nitrogen fertilizers in addition to P-K-L, however, materially decreased the proportion of white clover in the clipped forage. Thus there was more difference between the clover content of the P-K and the P-K-L plots than between that of the N-P-K and the N-P-K-L plots. Since white clover responds more to lime than do the grasses, it is not surprising that the greatest response to lime was obtained where conditions were most favorable for the presence of clover.

The relatively small increases in yield from superphosphate, potash, and lime during 1934 and 1936, compared with the increases during 1931-1933, undoubtedly are due at least partly to the less favorable growing seasons and to the small percentages of clover on the area. The latter can be accounted for partly by the unfavorable seasons.

When comparing the response to different amounts of nitrogen during different years, as shown in Figure 6, it should be remembered that with the 1/2N treatment all the nitrogen was applied in the spring, whereas with the 2N treatment half of the nitrogen was applied in the spring and half in midsummer. Moreover, the increase in yield from nitrogen fertilization depends partly on the frequency of cutting. If cutting is done shortly after applying the nitrogen, or if growing conditions are unfavorable because of low temperature or dry weather, there will be a relatively greater increase in the nitrogen content of the herbage than in the yield of herbage. If, on the other hand, the time of cutting is delayed and conditions are favorable for growth, the nitrogen will be utilized more for increased growth than for an increase in the nitrogen content of the herbage. This may partly account for the large increase in yield from the 2N treatment in 1931, since very good growth followed both the spring and the summer application of nitrogen. Moreover, the amounts of white clover on the area in 1931 were relatively

low. In 1932 there was so much white clover in the early spring that the response to nitrogen was relatively small, whereas in the latter part of the season it was too dry for efficient utilization of the summer application of nitrogen. The 1933 season was unusually good for pasture

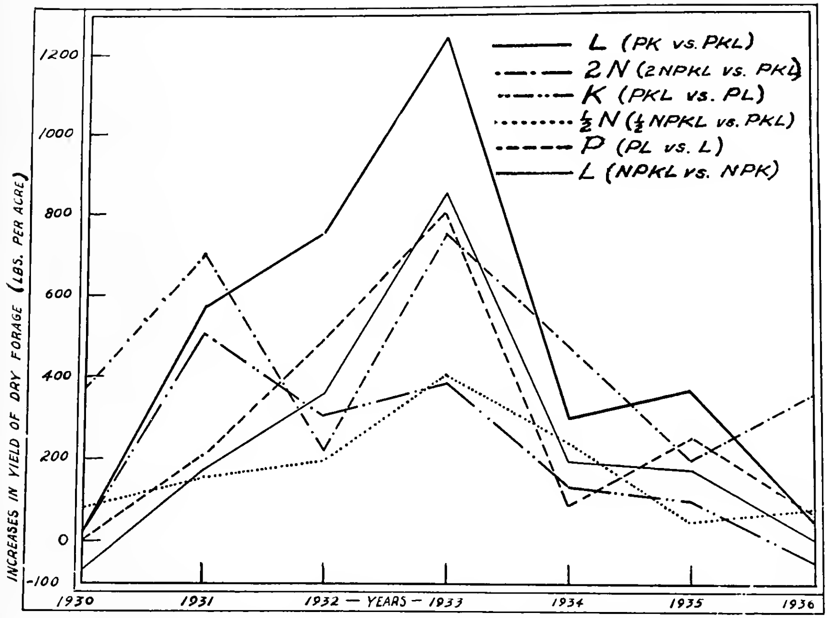


FIG. 6. INCREASES IN YIELDS OF DRY FORAGE FROM VARIOUS FERTILIZER ELEMENTS ON THE DEKALB SILT LOAM AT MORGANTOWN [ALL PLOTS RECEIVING THE DIFFERENT SOURCES OF NITROGEN WERE CONSIDERED IN DETERMINING THE RESPONSE TO L (NPKL vs NPK)]

growth and there was a large increase in yield from heavy nitrogen fertilization. Moreover, more than half of the increase occurred following the summer application of nitrogen on June 30 in spite of a rather high percentage of white clover on the area during that period. During 1934 the season was very dry until the latter part of July (Figure 1) and there was little response to the spring application of nitrogen. Over one-half of the increase from the 2N treatment occurred during a period of rainy weather in late July and August. The poor response to nitrogen in 1935, when there was relatively little clover, is attributed partly to the cold weather in the early spring, together with the dry weather during the latter part of the summer. The increase in yield from nitrogen fertilization was also small during the very dry season of 1936.

Aurora Experiment

The yields of forage clipped from the various lime and fertilizer treatments on the Upshur soil at Aurora are summarized in Table 15. No significant increase was noted in yield from the use of lime on this

Table 15—*Yields of forage from the various fertilizer and lime treatments on the Upshur clay loam at Aurora*

Plot No.	Treatment[1]	Dry forage (Lb. per acre)								Average Increase (%)
		1930	1931	1932	1933	1934[2]	1935	1936	Average	
3, 8, 13	None	409	661	489	344	302	419	293	417	...
1	P	588	1064	1112	1095	379	872	421	790	89
2	P-2L	518	994	1115	1199	317	910	397	778	87
4	P-K	465	1022	1038	1094	364	801	406	741	78
5	P-K-2L	429	767	1097	1280	346	758	304	711	71
6	N-P-K	712	1336	1401	1670	425	912	453	987	137
7	N-P-K-2L	802	1588	1556	1951	416	928	412	1093	162
9	N-P-K-L	725	1645	1456	1823	382	957	464	1064	155
10	2L	419	812	593	433	309	443	284	470	13
11	1/2N-P-K-2L	650	1312	1516	1777	423	988	414	1011	142
12	2N-P-K-2L	869	1930	1560	2221	513	1119	513	1246	199
14	2N-2P-K-2L	909	1985	1576	2563	480[3]	1283	649	1363	227
15	N-2P-K-2L	740	1835	1530	2150	522[3]	1263	536	1225	194

[1]See Tables 2 and 4 for more detailed description of treatments.
[2]The area was grazed during the latter part of the 1934 season and consequently the yields are for the period prior to July 1.
[3]Average of only three plots.

Table 16—*Yields of forage from the various fertilizer and lime treatments on the Huntington silt loam at Moorefield*

Plot No.[1]	Treatment	Dry forage (Lb. per acre)							Average increase (%)
		1930	1931	1932	1933	1934	1935	Average	
3, 8, 13	None	643	1781	729	1674	842	1150	1136	...
1	P	699	1908	808	2144	1154	1386	1350	19
2	P-2L	776	2013	949	2846	1252	1591	1571	38
4	P-K	707	1968	922	2634	1275	1489	1499	32
5	P-K-2L	686	1998	951	2949	1390	1405	1563	38
6	N-P-K	808	2516	1168	2876	1568	1736	1779	57
7	N-P-K-2L	866	2458	1237	3030	1448	1852	1815	60
9	N-P-K-L	902	2442	1160	2778	1353	1811	1741	53
10	2L	604	1704	769	2097	903	1192	1211	7
11	1/2N-P-K-2L	829	2151	1112	2865	1338	1600	1649	45
12	2N-P-K-2L	1001	2144	1488	3420	1681	2065	2133	88
14	2N-2P-K-2L	1000	3188	1474	3682	1802	2119	2211	95
15	N-2P-K-2L	912	2596	1272	3315	1465	1807	1894	67

[1]All plots are in quadruplicate. See Tables 2 and 4 for more detailed treatments.

soil, although the pH of the unlimed soil was about 5.4. Muriate of potash also gave no increase in yield. Superphosphate alone increased the yield 89 percent, and the 2N-2P-K-2L treatment produced an average increase of 227 percent. Since neither lime nor potash gave any increase in yield, this 227 percent increase must have been due to the superphosphate and nitrogen fertilizers. The average increase in yield from the 2P treatment, compared with the P treatment, was relatively small. A comparison of the yields during different years, however, shows that for the first three years the P treatment was as effective as the 2P treatment, but thereafter there were marked increases in yield from the additional amount of superphosphate.

The increases in yield from the various fertilizer elements, calculated in the same way as for the Morgantown experiment, are given in Figure 7. The response to superphosphate increased rapidly during the first four years, when there were rapid increases in the percentage of Kentucky bluegrass and white clover. There was but little increase in yield from superphosphate during the very dry years of 1934 and 1936, the increase in 1934 being especially low because, as shown in Table 15,

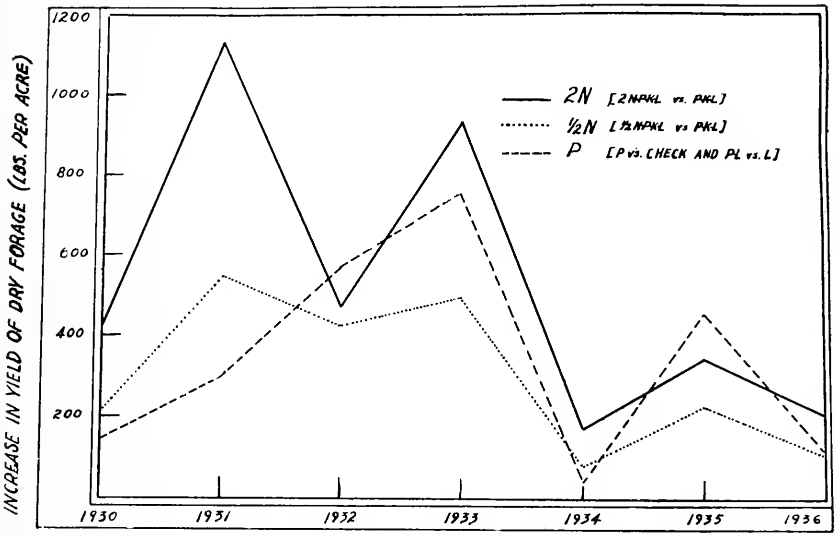


FIG. 7 INCREASE IN YIELD OF DRY FORAGE FROM SUPERPHOSPHATE AND NITROGEN ON THE UPSHUR CLAY LOAM AT AURORA (LIME AND POTASH WERE OMITTED, BECAUSE THEY GAVE NO INCREASE ON THIS SOIL)

no yields were obtained after the first of July. There was considerably more rainfall in 1935 than in 1934 or 1936 (Fig. 1), and the response to superphosphate was considerably greater.

The increases in yield from nitrogen fertilization were dependent largely upon the season. In 1930 there was a good response during the

early part of the season. The months of July, August, and September were very dry, however, and since the total yields during this period were small, there was little response to nitrogen. In 1931, with good growing weather and but little clover until late in the season, there was a very marked response to nitrogen fertilization. The marked response in 1932 to the 1/2N treatment is rather surprising in view of the excellent stand of white clover. The relatively smaller increase in yield from the 2N treatment in 1932 is attributed partly to the extremely dry weather following the summer application of nitrogen and partly to the high percentage of white clover on the area. (As was pointed out earlier, the 2N treatment decreased the percentage of clover but the 1/2N treatment did not.) During 1933 there was also a marked response to nitrogen fertilizer, but the increase occurred almost entirely before the first of June, when clover was not a very important factor. After June 1 the percentage of clover was so high on the P-K-L plots that there was little further increase in yield from nitrogen fertilizer. The seasons of 1934 and 1936 were so dry that there was little growth on any of the plots and consequently the increases in yield from nitrogen fertilization were small. Moreover, as explained previously, no yields were obtained in 1934 after the first of July. The reason for the relatively small response to nitrogen fertilizers in 1935 is not known.

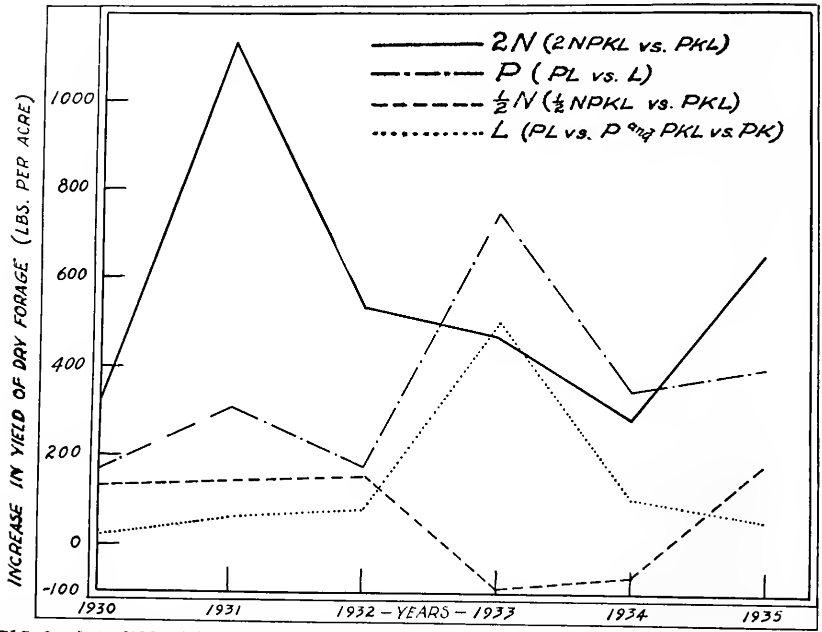


FIG. 8 INCREASES IN YIELDS OF DRY FORAGE FROM VARIOUS FERTILIZER ELEMENTS ON THE HUNTINGTON SILT LOAM AT MOOREFIELD.

Moorefield Experiment

Table 16 gives a summary of the yields of forage obtained on the Huntington soil at Moorefield. As was stated earlier, this soil is much more fertile than the ones at Morgantown and at Aurora (see Table 1). This is also apparent from the relatively high yields of the untreated plots. The percentage increases in yield from fertilization and liming, therefore, were much lower than at Morgantown or at Aurora, although the actual increases in yield were about the same. The average increases in yield from the 2L, P, P-2L, and 2N-2P-K-2L treatments were 7, 19, 38, 38, and 95 percent, respectively.

The increases in yield from the various fertilizer elements are shown in Figure 8. During the first three years, when there was but little clover on the area, the increases in yield from superphosphate were small. During 1933, however, with a high percentage of white clover and unusually good growing weather, there was a large increase in yield from superphosphate. In 1934, with considerable white clover in the spring but with a short growing season due to dry weather, the actual increase in yield was much smaller than in 1933, although the percentage increase was about the same. There was also a substantial increase in yield in 1935, when there was relatively little clover, but the percentage increase was somewhat less than in 1933 and 1934.

Lime increased the yield when white clover was abundant but had no apparent effect on the growth of Kentucky bluegrass other than that resulting from increased growth of clover.

It is interesting to note that when clover was absent the increases in yield from the 1/2N treatment were surprisingly uniform, averaging about 150 lb. per acre, whereas during the two years when clover was present the same treatment decreased the yield, presumably because of decreasing the percentage of clover.

The 2N treatment gave a large increase in yield in 1931, when rainfall was well above normal and when clover was absent. The smaller increase in 1933 was due largely to the high percentages of clover on the plots receiving no nitrogen fertilizer. The poor response to the 2N treatment in 1934 is attributed partly to the presence of clover during the early part of the season and partly to the prolonged dry period during the summer. In 1930, 1932, and 1935 the small increases were due partly to the relatively poor growing weather following the summer applications of nitrogen; in 1932 no cuttings were made after that time.

As was noted earlier, even the 100-lb. application of nitrate of soda decreased the percentage of clover on the Moorefield experiment. This decrease in the percentage of clover explains the decrease in yield during the years when clover was abundant. With heavy nitrogen fertilizer, however, the increased growth of Kentucky bluegrass more than overbalanced the effect of the decrease in clover. Thus it appears that on a good sod of Kentucky bluegrass, even light applications of nitrogen may stimulate the growth of Kentucky bluegrass and thereby crowd out

Table 17—*Yields of forage from the various fertilizer treatments on the Westmoreland silt loam at Maidsville*

Plot No.[1]	Treatment[2]	Dry forage (Lb. per acre)							Average increase (%)
		1931[3]	1932	1933	1934	1935	1936	Average	
1, 4, 10, 16	None	1940	1162	1103	622	850	806	1080	..
2		2186	1412	1635	694	955	889	1295	20
3	**P-K**	2199	1277	1658	655	890	775	1242	15
5	N-P (Mar. 100) (June 100)	2238	1614	2358	1054	1360	1129	1625	50
6	N-P-K (Mar. 200)	2618	1684	2342	1095	1388	1137	1711	58
7	N-P-K (Mar. 100) (June 100)	2357	1661	2406	985	1347	1151	1651	53
8	N-P-K (Mar. 100) (July 100)	2542	1586	2359	1004	1214	1043	1625	50
9	N-P-K (Mar. 100) (June 50) (Aug. 50)	2424	1554	2603	1074	1475	1218	1725	60
11	N-P-K (Mar. 50) (June 100) (Aug. 50)	2530	1525	2330	955	1396	1154	1648	53
12	N-P-K (Mar. 50) (June 50) (July 50) (Aug. 50)	2870	1561	2590	1191	1367	1218	1799	67
13	N-P-K (Mar. 100) (June 100)	2615	1552	2143	1053	1523	1164	1725	60
14	1/2N-P-K (Mar. 100)	2600	1513	2008	785	1243	1037	1531	42
15	1/2N-P-K (Mar. 50) (June 50)	2567	1513	2228	858	1221	991	1563	45
17	1/2N-P-K (June 100)	2305	1372	2012	873	1256	1081	1483	37
18	1/2N-P-K (June 50) (Aug. 50)	2465	1401	2279	818	1256	1053	1545	43
Average for P and K plots		2192	1344	1646	674	922	832	1268	17
Average for all 1/2NPK plots		2484	1450	2132	833	1244	1040	1530	42
Average for all N-P-K plots		2524	1592	2429	1051	1384	1152	1698	57

[1]All plots are in quadruplicate.
[2]The distribution of the nitrate of soda is indicated in parenthesis. Thus (Mar. 100) means 100 lb. per acre of nitrate of soda in March. P and K have same meaning as described in Table 2.
[3]Exclusive of the period June 20-July 15.

part of the clover. It should be recognized, however, that the height and frequency of clipping are also important factors determining the relative percentages of Kentucky bluegrass and white clover. Under good grazing practices where the grass is not allowed to get very high, the nitrogen would probably have had a much lesser effect in reducing the percentage clover than under the conditions of these experiments.

This area received a deposit of from 2 to 5 in. of silt during the flood in March 1936; consequently the studies were discontinued.

Maidsville Experiment

The yields of forage from the various fertilizer treatments on the Westmoreland silt loam at Maidsville are given in Table 17. Potash gave no increase in yield on this soil, and the increase from superphosphate alone was relatively small, averaging only 20 percent. Unfortunately, the response to superphosphate was not determined on plots receiving nitrogen fertilizer. The increase would no doubt have been considerably greater had available nitrogen not been an important limiting factor. As shown in Figure 9, the greatest increase in yield from phosphorus was obtained during 1933, which season was very favorable for pasture growth. The season of 1931 was also favorable, but the superphosphate had not had time to penetrate into the soil and become available to the plants. The small increases in yield from superphosphate in 1934 to 1936 appear to be due partly to the unfavorable

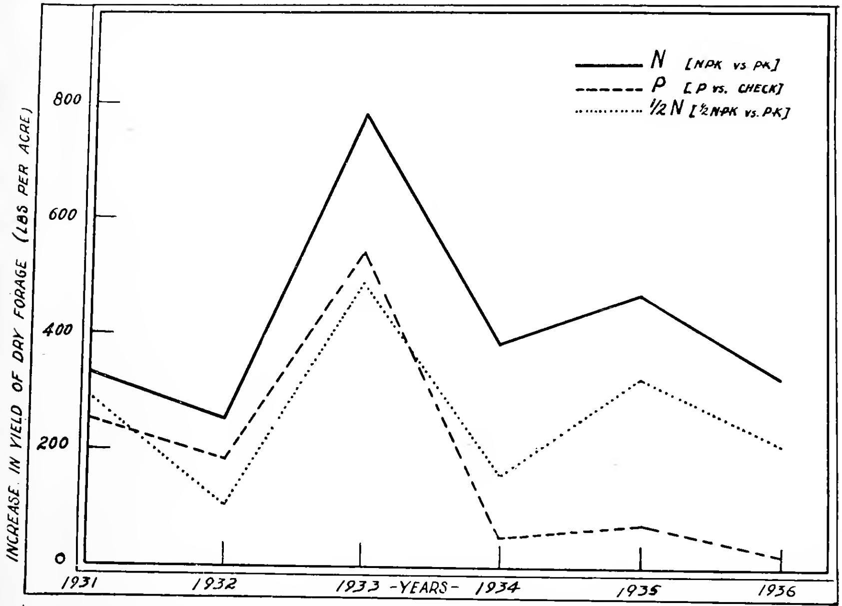


FIG. 9 INCREASE IN YIELDS OF DRY FORAGE FROM VARIOUS FERTILIZER TREATMENTS ON THE WESTMORELAND SILT LOAM AT MAIDSVILLE.

seasons and partly to a marked deficiency in available nitrogen on the plots where the response to superphosphate was determined. Practically no white clover was present on the plots after 1933, the early summer drought of 1934 having killed the clover.

There were marked increases in yield from nitrogen fertilization. The average increase in yield per unit of nitrogen fertilizer was about the same regardless of the time of application.

Wardensville Experiment

The small plot experiment at Wardensville was discontinued temporarily after the spring of 1934 because of injury from moles and dry weather and the consequent appearance of numerous weeds. The yields obtained during 1932 and 1933 are summarized in Table 18. As was stated earlier, white clover was abundant in 1932 and absent in 1933. This difference in botanical composition had a marked effect on the response to lime and fertilizer treatments. In 1932 there were marked increases in yield from lime and superphosphate (83 percent) but no increase from nitrogen fertilization except where large amounts had been applied. On the other hand, in 1933 the increase from phosphorus and lime was only 16 percent, whereas with the addition of nitrogen (N) it was raised to 55 percent, and the increase in yield from the 2N-P-K-L treatment was 103 percent. Muriate of potash gave an additional in-

TABLE 18—*Yields of forage from the various fertilizer and lime treatments on the Monongahela fine sandy loam at Wardensville*

Plot No.[1]	Treatment	Dry forage (Lb. per acre)		Percentage increase in yield	
		1932	1933	1932	1933
3, 8, 13, 18, 23	None	1105	993	...	...
1	P	1607	1187	45	20
2	P-2L	2021	1148	83	16
4	P-K	1516	1078	37	9
5	P-K-2L	2161	1189	96	20
6	N-P-K	1860	1648	68	66
7	N-P-K-2L	2280	1639	106	65
9	N-P-K-L	2137	1718	93	73
10	2L	1377	1054	25	6
11	1/2N-P-K-2L	2416	1392	119	40
12	2N-P-K-2L	2518	2018	128	103
14	2N-2P-K-2L	2776	2303	151	132
15	N-2P-K-2L	2619	1728	137	74
16	Ammo-phos-K	1771	1640	60	65
17	Ammo-phos-K-2L	2195	1636	99	65
19	N-P-K (Sulfate of ammonia)	1666	1564	51	58
20	N-P-K-2L (Sulfate of ammonia)	2246	1735	103	75
21	N-P-K (Calnitro)	1841	1606	67	62
22	N-P-K-2L (Calnitro)	2124	1601	92	61
24	N-P-K (Urea)	1524	1467	38	48
25	N-P-K-2L (Urea)	2088	1514	89	52
26	N-P-2L	2042	1538	85	55

[1]All plots are in quadruplicate. See Tables 2 and 4 for more detailed description; also Table 5, second footnote.

crease over lime, phosphorus, and nitrogen of 21 percent in 1932, when clover was abundant, and of 10 percent in 1933, when clover was absent. In addition to the small-plot experiment there were also established in this area large plots of 4½ to 6 acres, where the response to fertilization and liming was measured by grazing. Some of the results of this experiment have been reported in another publication *(10)*, but it should be emphasized here that the percentage increases in yields from various treatments were very similar for the clipped and for the grazed plots.

Palestine Experiment

The yield data from the Palestine experiment are given in Table 19. The surprising feature of these results is the very high yields obtained in 1935 from the untreated plots which, as shown in Table 1, are very low in fertility. Since these high yields were due largely to the growth of lespedeza, they show the importance of this species for unproductive soils. Superphosphate alone, however, gave an increase in yield of 57 percent during the first season after treatment, showing that lespedeza responds well to fertilization. There was a marked additional increase in yield from nitrogen fertilizer and a small increase from the use of lime, but little or no response from potash. In 1936 the season was so dry that the yields were very low on all plots, and the increases in yield considerably less than in 1935.

Yield data are not reported for the Spencer experiment, since the yields from replicated plots were quite variable and since only two years' data are available.

TABLE 19—*Yields of forage from the various fertilizer and lime treatments on the Holston silt loam at Palestine*

Plot No.[1]	Treatment	Dry forage (Lb. per acre)		Percentage increases in yield	
		1935	1936	1935	1936
3, 8	None	1698	531	...	..
1	P	2668	669	57	26
2	P-L	2732	601	61	13
4	P-K	2580	661	52	24
5	P-K-L	2726	693	61	31
6	N-P-K	3014	749	78	41
7	N-P-K-L	3159	816	86	54
9	N-P-K-2L	3577	828	111	56
10	L	1868	553	10	4
12	N-P-L	3241	830	91	56
13	1/2P-L	2554	569	50	7
14	1/2P-1/2K-L	2735	670	61	26

[1]All plots are in quadruplicate. See Tables 3 and 4 for more detailed treatments.

FACTORS TO BE CONSIDERED IN INTERPRETING THE YIELD AND OTHER DATA

In order to get a proper understanding of the response of permanent pastures to fertilization and liming, particularly as measured by the weight of clippings, it is necessary to consider three important points: (1) The residual effect of lime and fertilizers over a number of years

is considerable, (2) yield data alone do not shoow the difference in the kind of herbage and in the nutritive value of the herbage found on treated and untreated plots, and (3) plots clipped with a lawnmower may show lower yields and lower amounts of desirable species than grazed plots, since no manure is returned.

Residual Effect of Lime and Fertilizer

In order properly to evaluate the results obtained from experiments with fertilizer and lime on permanent pastures, it is necessary to know not only the increase obtained during the first few years but also the residual effect of the fertilizer and lime. The importance of this residual effect is shown by an experiment started on the Dairy Husbandry Farm at Morgantown in 1923. At that time 88 0.05-acre plots were established on an old upland pasture and topdressed with various combinations of lime, fertilizer, and manure, with and without reseeding. From 1924-1928 inclusive, one-half of each plot was protected from grazing and the yield of hay and aftermath determined. The other half of each plot was grazed but no yields determined. Periodic botanical estimates were made on both the grazed and the ungrazed areas. The results of this study were published in 1930 *(5)*. The plots, however, are still in permanent pasture. On a part of this area no lime has been applied since 1923 and no fertilizer or manure since 1927. Studies of the residual effect of the lime and fertilizer on the botanical composition, the yield of clipped forage, and the acidity and available phosphate content of the soil are being conducted. Only a summary of some of the data obtained will be reported here.

The residual effect of lime and phosphorus on the botanical composition of the vegetation in the fall of 1936 is shown in Table 20. The untreated plots averaged 7 percent desirable species as compared with 40 percent for the plots that received lime in 1923. The residual effect of the phosphorus is much smaller that that of lime but is probably as great as could be expected because the phosphorus treatment consisted of only 600 pounds of 16% superphosphate applied half in 1923 and half in 1927. On the basis of the botanical estimates the carrying capacity was calculated, using the standard proposed as a result of other

Table 20—*Residual effect of lime and superphosphate applied as a topdressing to a permanent pasture, nine to thirteen years previously*

Fertilizer treatment[1]	No. of plots averaged	Total desirable species in 1936[2] (%)	Calculated carrying capacity[3] (Acres per animal unit)
None	5	7	5.5
L	5	40	3.0
P	6	14	5.0
P-L	6	50	2.5

[1]P = 600 lb. per acre of 16% superphosphate applied half in 1923 and half in 1927.
L = 3000 lb. per acre of hydrated lime in 1923.
[2]Kentucky bluegrass with small amounts of red top and white, red, and hop clovers.
[3]Based on standard by which the carrying capacity can be estimated directly from the percentage of total desirable species *(7)*.

investigations *(7)*. By means of this standard the carrying capacity can be estimated directly from the percentage of total desirable species. The results (Table 20) indicate that the carrying capacity of the plots that received phosphorus and lime is still about twice as high as that of the untreated plots.

The reason for the large residual effect from lime is evident from the soil acidity data presented in Figure 10. Where no lime had been applied since 1923, the surface 0-1½ in. of soil had a pH of 5.23, and the lower layers approximately pH 5.0. In contrast, the pH value of the limed plots was 6.98 in the surface 0-1½ in., and the pH of the lower layers 5.57 to 6.31. Thus it is evident that although some of the lime has penetrated into the soil sufficiently to lower the acidity of the 5-7 in. layer, most of it has remained to neutralize the surface layers where the roots of the pasture plants are most abundant.

In the present experiments the residual effect of lime and superphosphate as measured by soil analysis was determined in 1934. Some of the results obtained at that time are summarized briefly in Table 21. The 2L treatment increased the pH of the surface 1½-in. layer of soil from 5.71 to 6.79 at Moorefield and from 5.32 to 6.42 at Aurora. The L

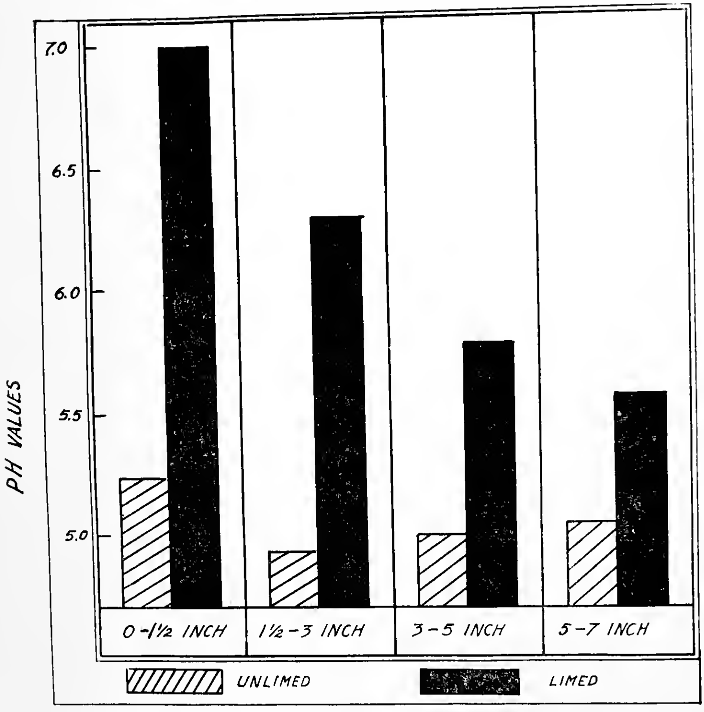


FIG. 10 THE RESIDUAL EFFECT OF A TOP DRESSING OF 1½ TONS OF HYDRATED LIME ON THE PH VALUES OF THE SOIL AT DIFFERENT DEPTHS THIRTEEN YEARS AFTER APPLICATION.

Table 21—*Effect of topdressings of lime and fertilizer on the pH and available phosphorus of the soil at different depths*[1]

Soil treatment	MOOREFIELD EXPERIMENT Huntington silt loam			MORGANTOWN EXPERIMENT Dekalb silt loam			AURORA EXPERIMENT Upshur silt loam		
	0-1½″	1½-3″	3-5″	0-1½″	1½-3″	3-5″	0-1½″	1½-3″	3-5″
				pH VALUES					
Unlimed plots	5.71	5.61	5.60	4.97	5.09	5.38	5.32	5.19	5.38
Limed plots[2]	6.79	6.02	5.71	6.29	5.39	5.47	6.42	5.63	5.46
				READILY AVAILABLE PHOSPHORUS[3]					
No P plots	35	12	10	16	6	5	12	6	6
P plots	116	23	11	77	13	7	41	14	8
2P plots	275	47	24	158	24	8	125	24	8

[1]The soil samples from Morgantown and Moorefield were taken in the spring of 1934, whereas those from Aurora were taken in the fall of 1933.

[2]2L at Moorefield and Aurora; L at Morgantown.

[3]Determined by Truog's laboratory method *(11)* and expressed as pounds per 2 million lb. of soil.

treatment at Morgantown increased the pH of the surface layer from 4.97 to 6.29. The effect of the lime on the 1½-3-in. soil layer, however, was much smaller than in the surface 1½-in. layer. The penetration of lime below the 3-in. level was negligible. Similarly, the superphosphate treatment resulted in large increases in readily available phosphorus in the surface layer of soil, but had no significant effect in the 3-5-in. layer. These results are in agreement with those reported by Brown and Munsell *(1, 2)*. It is obvious, therefore, that pasture soils do not lose any appreciable amount of lime or phosphorus through leaching. It should also be recognized that much of the lime and phosphorus that is removed by the plant under grazing conditions is returned to the soil in the manure. Part of the phosphorus added in fertilizers, however, becomes fixed in the soil in an unavailable form.

From these data it is evident that the cost of improving permanent pastures by the use of lime and superphosphate cannot be charged to the benefits obtained during the first few years. The residual effect of the lime may be considerable for more than 20 years. This does not mean, of course, that more lime need not be added during the period, but that the amounts needed will be relatively small. Once a good bluegrass and clover sod has been reestablished, the cost of maintaining it should be low as compared to the initial treatment.

Effect of Lime and Fertilizer on Quality of Herbage

It is well recognized that grazing animals will do much better on some pastures than on others, regardless of the amount of feed available. High yields therefore are not the only considerations in a pasture program. As was shown in Tables 5 and 6, the vegetation of the untreated and poorly treated plots of these experiments consists mostly of poverty grass and weeds, whereas that of the plots treated with phosphorus and lime or with a complete fertilizer consists to a considerable extent of Kentucky bluegrass and other desirable species. Not only are bluegrass, white clover, and other desirable species more palatable than most weeds and such grasses as broomsedge and poverty grass, but they have greater nutritive value *(8)*.

The nutritive value of pasture herbage can best be determined by feeding experiments, yet there are certain basic requirements that can

TABLE 22—*Phosphorus, calcium, and protein content of the air-dry herbage from certain plots on the Morgantown and Moorefield experiments*[1]

Fertilizer and lime treatment[2]	Morgantown experiment			Moorefield experiment		
	Phosphorus %	Calcium %	Protein %	Phosphorus %	Calcium %	Protein %
None	0.168	0.67	10.9	0.280	0.58	13.6
P-K-L	0.278	0.99	14.6	0.337	0.71	14.8
2N-P-K-L	0.263	0.92	15.5	0.331	0.51	15.6
2N-2P-K-L	0.337	0.98	16.0	0.361	0.55	16.0

[1]Average of 5 years at Morgantown (4 years for the 2N-2P-K-L treatment) and 4 years at Moorefield.
[2]All treatments are in quadruplicate.

be determined by chemical methods. Henderson and Weakley *(3)* found that for growing dairy animals, "rations which contain less than 0.35 percent of calcium or less than 0.20 percent of phosphorus give rise to a bone which is low in ash and consequently high in moisture and extractable material." For high producing dairy cows Huffman *et al.* *(1)* found that even 0.20 percent phosphorus in the ration is inadequate.

The average phosphorus, calcium, and protein contents of the herbage from certain plots at Morgantown and at Moorefield are summarized in Table 22. Herbage from the untreated plots at Morgantown averaged only 0.168 phosphorus, which is below the minimum value of 0.20 found to be necessary for growing dairy cattle. The use of liberal amounts of fertilizer doubled the phosphorus content of the herbage. The calcium content of the herbage from the untreated plots averaged 0.67 percent, which appears to be adequate for grazing purposes. A more detailed study *(8)*, however, shows that the high percentage of calcium in the herbage of the untreated plots is due to the high calcium content of the weeds and that the poor native grasses from these plots contain much less than 0.35 percent calcium. The P-K-L treatment increased the protein content of the herbage from 10.9 to 14.6, an increase of 34 percent. This increase was due largely to the increase in the amount of white clover in the herbage. Nitrogen fertilization, in addition to P-K-L, gave an additional increase in the protein content of the herbage. The effect of nitrogen fertilizers, however, will be discussed more fully in another publication.

At Moorefield, with a more productive soil and a more desirable type of vegetation, the phosphorus content of the herbage from the untreated plots was much higher than at Morgantown, averaging 0.280 percent. There was still a very marked increase, however, from the use of phosphate fertilizer. The calcium content of the herbage was increased from 0.58 percent to 0.71 percent by the P-K-L treatment, but nitrogen fertilization produced a marked decrease due largely to a decrease in the percentage of clover. Both the P-K-L and the complete fertilizer treatments gave substantial increases in the protein content of the herbage.

Relation Between Yields From Clipping and From Grazing

Another consideration that must be remembered in interpreting the results of pasture fertilizer experiments is that under clipping conditions all the herbage is removed, whereas under grazing a large portion of the fertilizer elements in the herbage is returned to the soil in the manure. The result, as shown from the data obtained at Wardensville and published in detail elsewhere *(10)*, is that the yields from clipped plots gradually decrease over a period of years as compared with those obtained by grazing. Therefore the actual increases in yield of harvested herbage, as shown for the various treatments in Tables 14 to 19, inclusive, are lower than would be obtained under grazing conditions. The percentage increases in yield obtained by clipping with a lawn-

mower, however, were found to be very similar to those obtained by grazing *(10)*. Thus it appears that the percentage increase in yields of clipped plots can be used in estimating the increased carrying capacity of the pasture as a result of treatment, provided the carrying capacity of the untreated pasture is known. It is on this basis that the yields obtained in this investigation will be interpreted.

It is realized that this method of interpreting the results of clipping experiments is subject to certain errors and also that it may not apply to all pastures. In general, however, it is believed that the percentage increases in yield determined in this manner would be underestimated rather than overestimated, especially on the poorer soils, where the herbage is largely poverty grass on the untreated plots as compared with Kentucky bluegrass and white clover on the limed and fertilized plots. Moreover, this method makes no allowance for the residual effect of the fertilizer and lime.

GENERAL CONSIDERATIONS AND INTERPRETATION OF RESULTS

In evaluating the benefits of a pasture-improvement program, due consideration must be given to the effect of the program on the farm unit as a whole. If a farmer doubles the carrying capacity of his pasture through the use of lime and fertilizer, he should not overlook the importance of making the most efficient use of that extra feed. Some farmers might find it most profitable to increase the size of their herd, whereas others would find it more profitable to give major consideration to decreasing the amount spent for supplementary feed. The latter view might also involve a change in the ratio of crop land to pasture. Thus it appears that any monetary interpretation of the results would have only a very general application.

TABLE 23—*Summary and interpretation of the yields of forage from the experiment on the Dekalb silt loam at Morgantown*

Plot treatment	Relative yields of clipped forage	Estimated carrying capacity[1] (Acres per animal unit)	Estimated feed value (Lb. per acre of alfalfa hay)[2]	Average annual cost per acre of lime and fertilizer[3] (dollars)
None	100	5.0	800	...
L	119	4.2	950	1.03
P	136	3.7	1080	1.64
P-L	164	3.1	1290	2.67
P-K-L	199	2.5	1600	3.33
N-P-K	192	2.6	1540	5.16
N-P-K-L	236	2.1	1910	6.06
1/2N-P-K-L	228	2.2	1820	4.70
2N-P-K-L	272	1.8	2220	9.02
2N-2P-K-L	288	1.7	2350	10.63
N-2P-K-L	258	1.9	2100	7.67

[1]Assuming that 5 acres per animal unit would be required for the untreated area and that the percentage increases from clipping are the same as would have been obtained by grazing *(7, 10)*.

[2]Based on 4000 lb. of alfalfa hay per animal unit.

[3]If allowance were made for the residual effects the cost would be much smaller.

In view of these considerations the effect of lime and fertilizer treatments will be interpreted in terms of (1) the increase in the estimated carrying capacity of the pasture, and (2) the feed value of the estimated increase in terms of alfalfa hay. The results of this interpretation are summarized in Tables 23 to 26 inclusive. (The Wardensville, Spencer, and Palestine experiments were omitted in this summary because the yields are available for only two years.)

On the Morgantown experiment $3.33 per acre per year for lime, superphosphate, and muriate of potash increased the estimated carrying capacity from 5.0 acres per animal unit to 2.5 acres per animal unit (Table 23).* When converted to alfalfa hay-equivalent this means 800 pounds per acre per year from the unfertilized plots as compared with 1600 pounds from the fertilized plots. In addition, as already shown, the lime and fertilizer will continue to give marked increases in yield for a number of years. At Aurora (Table 24) $1.64 per year for superphosphate increased the calculated carrying capacity from 4.5 acres per animal unit to 2.4 acres per animal unit. Expressed in alfalfa hay-equivalent the increase amounted to 780 pounds per acre per year. The increase from lime and superphosphate at Aurora was not as economical as the increase from superphosphate alone because, as already noted, this pasture did not respond to lime. At Moorefield $2.65 for lime and superphosphate gave an estimated increase of 960 pounds of alfalfa hay.

TABLE 24—*Summary and interpretation of the yields of forage from the experiment on the Upshur clay loam at Aurora*

Plot treatment	Relative yields of clipped forage	Estimated carrying capacity[1] (Acres per animal unit)	Estimated feed value (Lb. per acre of alfalfa hay)[2]	Average annual cost per acre of lime and fertilizer[3]
				(dollars)
None	100	4.5	890	...
2L	113	4.0	1000	1.25
P	189	2.4	1670	1.64
P-2L	187	2.4	1670	2.89
P-K-2L	171	2.6	1540	3.55
N-P-K	237	1.9	2100	5.16
N-P-K-L	255	1.8	2220	5.91
N-P-K-2L	262	1.7	2350	6.41
1/2N-P-K-2L	242	1.9	2100	4.98
2N-P-K-2L	299	1.5	2670	9.27
2N-2P-K-2L	327	1.4	2860	10.88
N-2P-K-2L	294	1.5	2670	8.02

[1]Assuming that 4.5 acres per animal unit would be required for the untreated area and that the percentage increases from clipping are the same as would have been obtained by grazing *(7, 10)*.

[2]Based on 4000 lb. of alfalfa hay per animal unit.

[3]If allowance were made for the residual effects the cost would be much smaller.

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*Prices charged for lime and fertilizer were as follows:

Limestone (100% calcium carbonate equivalent)	$ 4.00 per ton
Superphosphate (20%)	20.00 per ton
Muriate of potash	40.00 per ton
Nitrogen	.09 per pound

No charge was made for hauling and spreading, but on the other hand no credit was given for the residual effect of the lime and superphosphate. The cost of the lime and fertilizer plus interest at 5% was divided into annual payments, the final one coming due in the fall of 1936.

It is interesting also to note that in some cases complete fertilizer and lime appears to be about as profitable as mineral fertilizers and lime. This is particularly true on the Westmoreland silt loam where, as previously noted, the response to phosphate fertilizer was low because the plots had little clover, and there was a marked nitrogen deficiency. It should be recognized, however, that the residual effect of nitrogen fertilizer is very small compared with that of lime and superphosphate, and also that the expense of applying nitrogen is greater because it must be applied more frequently. Moreover, it is believed that because of several unusually dry seasons during the course of these experiments there has been considerably less clover on the plots than would ordinarily occur in a fertilized pasture. This would result in overestimating the returns from nitrogen fertilization and underestimating the returns from lime and superphosphate.

Another important consideration with nitrogen fertilization is whether or not the extra pasture produced can be efficiently utilized. Under average weather conditions the greatest increase in yield from nitrogen fertilization will occur when the nitrogen is applied in the spring. When applied at this time it gives the grass an early start and thus may advance the grazing season by a week or ten days. However, a part of the increases in yield from the spring application of nitrogen will come at the time of peak production of the pastures that do not receive nitrogen fertilizer, and very little if any increases in yield will be obtained during the latter part of the season. Moreover, if a pasture is lightly grazed during May and June, the use of nitrogen fertilizer in the spring will tend to crowd out white clover and consequently may actually decrease the yield during the latter part of the season. If nitrogen fertilizers are used in addition to phosphorus and lime, therefore, more attention needs to be given to good management practices.

In view of these considerations it appears that, in general, the most profitable returns on West Virginia pastures will result from the use of superphosphate and lime. On some soils potash may also be profitable. Nitrogen fertilizers in addition to lime and superphosphate may give profitable returns, particularly on a dairy farm, provided the extra pasture can be utilized efficiently. Nitrogen fertilizer need not be used, however, where there is a good stand of white clover, since the clover will supply nitrogen for the grass.

The farmer who has enough cattle to utilize the luxuriant spring growth in his permanent pasture, particularly when it is fertilized with nitrogen, will, of course, need meadow aftermath, second-growth alfalfa, or some other temporary pasture to supplement his permanent pasture during part of the season.

SUMMARY AND CONCLUSIONS

The effect of topdressings of lime and fertilizers on the botanical composition of pasture plots and on the yield and chemical composition of the clipped herbage was studied on seven permanent pastures in the

state, situated on different soil types. All the pastures except one supported a poor type of vegetation and were unproductive.

Topdressings of lime and fertilizer increased the percentage of desirable plants, particularly Kentucky bluegrass and white clover, even though only small amounts of these species were present at the beginning in most of the experiments. At the same time the percentages of weeds, poor native grasses, and bare ground were materially decreased. The first change in the vegetation was usually found to be an increase in the percentage of white clover. In some of the experiments, where the application of lime and fertilizers was followed by a season of favorable weather conditions, large increases in white clover occurred during the first year. In general, however, it took at least one year before the lime and phosphate treatments materially increased the percentage of white clover. The increase in the percentage of bluegrass was somewhat more gradual. It was most marked after white clover had become well established. Where nitrogen fertilizers were applied in addition to phosphorus and lime, however, marked increases in the percentage bluegrass often occurred even before clover was very abundant. Moreover, nitrogen fertilizers when used in addition to phosphorus and lime increased the percentage of bluegrass in the sod, especially in those years when clover was absent or had not been present for several years. The use of nitrogen fertilizers at rates equivalent to 32 and 64 pounds of nitrogen per acre, however, materially reduced the percentage of clover under the conditions of these experiments.

The increase in the percentage of white clover from the use of lime and of superphosphate on the various soils was found to be closely related to the acidity and available phosphorus content of the soils. Under average pasture conditions the soil should be limed to a pH value of at least 5.8 and that the available phosphorus content of the

TABLE 25—*Summary and interpretation of the yields of forage from the experiment on the Huntington silt loam at Moorefield*

Plot treatment	Relative yields of clipped forage	Estimated carrying capacity[1] (Acres per animal unit)	Estimated feed value (Lb. per acre of alfalfa hay)[2]	Average annual cost per acre of lime and fertilizer[3]
				(dollars)
None	100	1.5	2670	...
2L	107	1.4	2860	0.78
P	119	1.3	3080	1.87
P-2L	138	1.1	3640	2.65
P-K-2L	138	1.1	3640	3.40
N-P-K	157	1.0	4000	5.48
N-P-K-L	153	1.0	4000	5.88
N-P-K-2L	160	0.9	4440	6.26
1/2N-P-K-2L	145	1.0	4000	4.83
2N-P-K-2L	188	0.8	5000	9.12
2N-2P-K-2L	195	0.8	5000	10.95
N-2P-K-2L	167	0.9	4440	8.09

[1]Assuming that 1.5 acres per animal unit would be required for the untreated area and that the percentage increases from clippings are the same as would have been obtained by grazing *(7, 10)*.

[2]Based on 4000 lb. of alfalfa hay per animal unit.

[3]If allowance were made for the residual effects the cost would be much smaller.

soil should be at least 20 pounds per 2,000,000 pounds of soil if a good pasture is to be obtained.

The average increase in yields from lime and superphosphate varied from 38 percent on the relatively fertile Huntington soil to 87 percent on the Upshur clay loam. Where complete fertilizer was used in large amounts in addition to lime, the increase in yields was raised to as high as 227 percent on the Upshur clay loam soil.

The increases in yield from the various treatments were affected not only by the fertility of the soil but also by the season and by the presence of white clover. When clover was present in considerable amounts, large increases in yield were obtained on all plots from the use of superphosphate and lime, and on the Dekalb soil from potash; but relatively small increases were obtained from the addition of nitrogen fertilizers. When clover was absent, however, the increase yields from nitrogen were sometimes as great if not greater than from lime and superphosphate.

The use of lime and superphosphate materially increased the protein, the calcium, and particularly the phosphorus content of the herbage. This increase was still evident 4½ years after the last treatment. The main reason for the higher nutritive value of the herbage of the treated plots is that the vegetation has been changed from one consisting mostly of weeds and poor native grasses to one dominantly of bluegrass, with white clover present in favorable seasons.

Data are presented showing the large residual effect of lime and superphosphate treatments. In an old pasture experiment, where a very acid soil received 1½ tons of hydrated lime 13 years previously, no lime was needed for good growth of the desirable species. most of the lime still being present in the surface three inches of the soil. On the unlimed plots there was present only 7 percent of desirable species as compared with 40% on the limed plots. These data emphasize the importance of considering the costs of pasture fertilization and liming as a long-time investment. Although the initial cost of improving a depleted pasture may range from $5 to $10 an acre, it should be remembered that once

TABLE 26—*Summary and interpretation of the yields of forage from the experiment on the Westmoreland silt loam at Maidsville*

Plot treatment	Relative yields of clipped forage	Estimated carrying capacity[1] (Acres per animal unit)	Estimated feed value (Lb. per acre of alfalfa hay)[2]	Average annual cost per acre of fertilizer[3] (dollars)
None	100	3.0	1330	...
P	120	2.5	1600	1.87
N-P	150	2.0	2000	4.73
N-P-K	156	1.9	2100	5.48
1/2N-P-K	142	2.1	1910	4.05

[1]Assuming that 3.0 acres per animal unit would be required for the untreated area and that the percentage increases from clippings are the same as would have been obtained by grazing *(7, 10)*.

[2]Based on 4000 lb. of alfalfa hay per animal unit.

[3]If allowance were made for the residual effects the cost would be much smaller.

a good sod is reestablished, the cost of maintaining such a sod will b relatively low.

On the basis of these and other studies the effect of liming an fertilization of the pastures was interpreted in terms of the number o acres required to pasture one animal and the feed value of the pastu in terms of alfalfa hay. The interpretation, although subject to certai errors, is believed to be a very conservative measure of the effect of th treatment, particularly in the case of lime and superphosphate, becaus no allowance could be made for residual effects. Moreover, the metho of interpretation did not take into consideration the superior quality o the fertilized pasture.

Even with this conservative method of evaluating the results, th data show large returns from both lime and superphosphate in almos every case. The few exceptions merely emphasize the importance o having the soil tested before applying lime and fertilizer. It is obviou that no increases in yield will result from the use of lime if the soil i not very acid, and that a soil high in readily available phosphorus wi not respond to superphosphate. Moreover, if a soil is very deficien in available phosphorus, lime without phosphorus fertilization will no give a satisfactory return regardless of the degree of acidity. Similarly fertilizers will not take the place of lime.

The most profitable returns from the use of lime and fertilizer wi be on soils that are now unproductive but that have a high potentia productive capacity: i. e., soils that are acid and low in available phos phorus but not droughty, badly eroded, or on very steep slopes. Ordin arily a combination of lime and superphosphate will give the greates returns for the money invested. It should be recognized, however, tha the profits derived from pasture fertilization will depend not only upo the increases in the yield and quality of the herbage but also upon th value of the products sold. With normal prices for milk, nitroge fertilization in addition to lime and superphosphate may be profitabl on a dairy farm provided the additional feed is utilized efficiently. Th greatest net returns from a nitrogen fertilizer will probably be obtaine by applying it early in the spring in order to get early grazing and thu to decrease the amount of barn feeding.

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